THE UNIVERSITY OF ALBERTA

LANDSAT MSS IMAGERY AS A BASE FOR THEMATIC MAPPING

by

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A THESIS

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ABSTRACT

The development of orthophotography and the subsequent production of orthophotomaps has laid the groundwork for the amalgamation of photo image and map symbol image. Due to the inherent characteristics of aerial photography, orthophotomapping has necessarily been undertaken at large scale. The considerable cost of producing an orthophoto image of a regional area at small to medium scales has inhibited their production as well as their orthophotomap counterparts. The establishment of satellite born remote sensors aimed at the earth's surface has provided these small to medium scale, earth images. Data received from the LANDSAT system and reproduced in photographic form offer the cartographer and map user a new dimension in photo mapping. It is now possible to use low cost satellite imagery in the production of small to medium scale photo maps. One use of such photo maps incorporates the satellite image as a base for thematic mapping.

This study is an appraisal of the LANDSAT system and an evaluation of products produced by the system in light of conventional orthophoto materials. Thematic LANDSAT maps produced by two governmental agencies are reviewed and evaluated. Additional thematic LANDSAT maps incorporating the other standard cartographic techniques are constructed and evaluated. The construction of these maps takes place on two levels and at two scales: 1) a commercially produced LANDSAT map using a polychrome image printed at a scale of 1:250,000; and 2) the remainder of LANDSAT maps produced in manuscript form using a

monochrome image and photographically reduced to approximately 1:1,500,000 from the compile scale of 1:750,000. These maps are then evaluated and guidelines for the production of future thematic LANDSAT maps are developed. A direction for future study of thematic LANDSAT mapping is also indicated by this appraisal.

ACKNOWLEDGEMENTS

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CHAPTER 1

OBJECTIVES AND METHODOLOGY FOR THE STUDY OF LANDSAT IMAGERY AS A THEMATIC MAPPING BASE

1.1 Introduction

The launch of the Earth's first man-made satellite over twenty years ago was just the beginning in the development of satellites and satellite sensor systems. Advancements proceeded and more sophisticated, orbiting space platforms equipped with sensors aimed at the Earth, began collecting new data for all earth related deciplines. The more recently launched LANDSAT satellite system (now two satellites) is one such development. Although the intended use of LANDSAT data is focused on extraction and interpretation of earth data, the natural extension of this earth information extraction lies in the direct and immediate function of LANDSAT data to Cartography. Just as the development of orthophotographs in 1954 laid the framework for the orthophotomap, the development of LANDSAT imagery lays the framework for the direct utilization of satellite imagery as a mapping base. LANDSAT photo mapping has adopted the design and form of the previously accepted, annotated orthophotomap, primarily a topographic or a "balanced" type of maps.

The use of LANDSAT imagery as a thematic mapping base is relatively untried. The National Aeronautics and Space Administration (NASA) in the United States and the Canada Centre for Remote Sensing (CCRS) in Canada have each produced a 1:250,000 LANDSAT map with a minimum of

annotation (NASA, 1972; CCRS, 1974). The United States Geological Survey is presently publishing a mosaiced LANDSAT image-map series of the state of Florida (McEwen, Schoonmaker, 1975), however, little thematic enhancement is used on the images. A similar map series of the polar regions (excluding north and south of 9^{0}) is also being produced by the same agency in cooperation with the American Geographical Society and the National Science Foundation (MacDonald, 1974). Again, these photo-maps use a minimum of annotation and rely upon the LANDSAT image for communication. The U.S. Soil Conservation Service is also producing LANDSAT image, mosaic maps of conterminous United States and Alaska on an Alber's Equal Area Projection (Hooper, 1974; Anderson, 1975); these maps once again use little thematic map annotation. The Canada Centre for Remote Sensing is beginning the production of Canadian LANDSAT image mosaics. These LANDSAT mosaic maps have annotation only on the image boarders. Apart from these published maps many earth deciplines have begun using LANDSAT images and annotating them as they would conventional photography, thus producing a type of thematic LANDSAT map. All of the published LANDSAT maps have utilized a minimum of symbology in a conventional orthophotomap approach. This type of LANDSAT mapping is the first step to mapping a greater range of thematic topics with LANDSAT imagery, even topics which are not directly visible on the imagery. These socio-economic themes require considerably more symbology and of different types.

1.2 Objectives and Methodology

The primary objective of these LANDSAT photo-mapping experiments is to investigate the function in LANDSAT imagery as a base-map for more

complex, socio-economic themes. Since few image-maps of this type have been published it will be necessary to: (1) evaluate existing thematic LANDSAT maps that are representative of cartographic techniques previously employed; (2) construct and evaluate thematic LANDSAT maps using cartographic techniques that have not been previously employed; (3) determine if such maps are feasible and develop guidelines for the construction of future thematic LANDSAT maps; (4) and to define the best direction for the future development of thematic LANDSAT maps.

Evaluation of thematic LANDSAT image-maps will follow traditional methods with a comparison of conventional orthophotography and orthophotomaps to LANDSAT imagery and LANDSAT image-maps. The LANDSAT image-maps, in turn, will be considered with respect to conventional orthophoto mapping problems and limitations. Consideration must be given to photo image content and map symbology content as well as the design of these two elements. Scale and generalization in relationship to map symbology and image depiction must also be taken into account.

To determine the feasibility of thematic LANDSAT mapping and develop guidelines for construction of future LANDSAT maps, experimental thematic LANDSAT maps will be constructed at two different image formats. One in which the LANDSAT image is produced in a polychrome utilizing the printing of different MSS bands in different colours and secondly the use of a monochrome LANDSAT image as a thematic mapping base. Additionally two scales of image-maps will be constructed and evaluated: the 1:250,000 scale which can also be compared to other LANDSAT Maps produced by NASA and CCRS, and the 1:750,000 which could conceivably

be a suitable scale for atlas mapping using LANDSAT images. LANDSAT maps will be constructed for each of the cartographic techniques commonly employed to symbolize major categories of socio-economic themes. These include both quantative and qualitative representations. Guidelines for the development and construction of future LANDSAT maps should arise from production and evaluation of the thematic LANDSAT maps fabricated in these experiments. As well the investigation of the LANDSAT system and its cartographic applications should develop a possible direction for future study.

CHAPTER 2

THE LANDSAT SYSTEM

2.1 Introduction

The first of two earth resources technology satellites (LANDSAT I)[1] was launched on July 23, 1972. The satellite now circles the Earth in a near polar, sun-synchronous orbit at an altitude of approximately 910 Kilometres (576 miles statute). This orbit allows for an angle of illumination which varies only with the season of the year. Since the launch, LANDSAT I has completed over fourteen thousand orbits. Each orbit takes an average of 103 minutes to complete at a total of 14 orbits per day (Fig. 1) with 18 days to complete full earth coverage and start again on a new cycle. The new cycle has a ground trace overlapping the previous cycle. The amount of overlap is dependent on latitude and satellite pass with increasing overlap as the satellite approaches the poles. Areas within nine degrees of each pole are not imaged. LANDSAT I is still functioning beyond expectations and the second earth resources technology satellite, LANDSAT II has been launched on 22 January 1975. LANDSAT II is intended to replace LANDSAT I, but it is not yet fully operational. However, MSS imagery is being received from both satellites. A third LANDSAT satellite is being planned for the more distant future (CCRS, 1974, 1975).

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[1] The Earth Resources Technology Satellite (ERTS) system was officially designated "LANDSAT" in May of 1975.

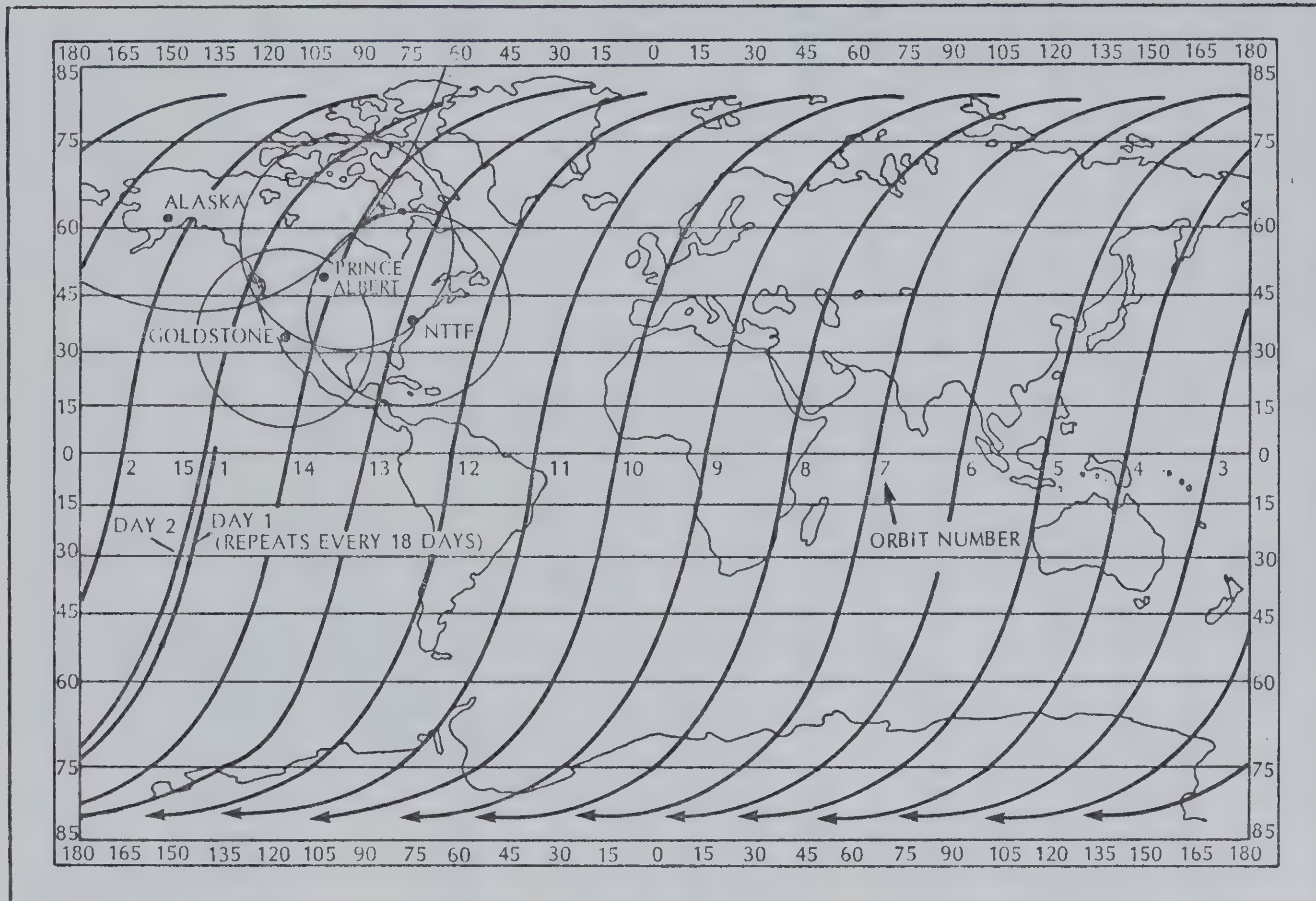


FIGURE 1

TYPICAL LANDSAT DAILY GROUND TRACE (Daylight Passes Only)

Due to the satellites orbital inclination, the areas within 9^{0} of the poles are not imaged.

The observation system of the spacecraft is divided into three sub-systems:

1) Data Collection
2) Return Béam Vidicon Camera and
3) Multispectral Scanner

Other systems exist on the spacecraft for attitude control, telemetry and maintenance of the satellite, however, these are the three systems with which records of earth data are made. Presently the Multispectral Scanner (MSS) is of prime importance to the cartographer. The Data Collection System (DCS) does not produce image products and the Return Beam Vidicon Camera System (RBV) was switched off early in the mission by NASA control and not reintroduced in LANDSAT II. Consequently, no imagery is being received from the RBV system at the present time.

The Multispectral Scanner (MSS) is the only operational imaging system remaining. It is a line scanning apparatus collecting earth data in four spectral bands with wavelengths as follows:

Sensor	Spectral Band No.	Wavelength in Nanometres (10^{-9} metres)	
*RBV	1	475-575	
	2	580-680	
	3 all bands solar reflected wavelengths	690-830	
MSS	4	500-600	visible green to orange
	5	600-700	visible orange to red
	6	700-800	deep red to near infrared
	7	800-1000	near infrared

*Return Beam Videcon Camera bands included for reference.

The size and weight of hardware have inhibited the inclusion of a full infrared channel.

As the satellite progresses along its orbital path the MSS system scans continuously in all four bands. The across track scan is

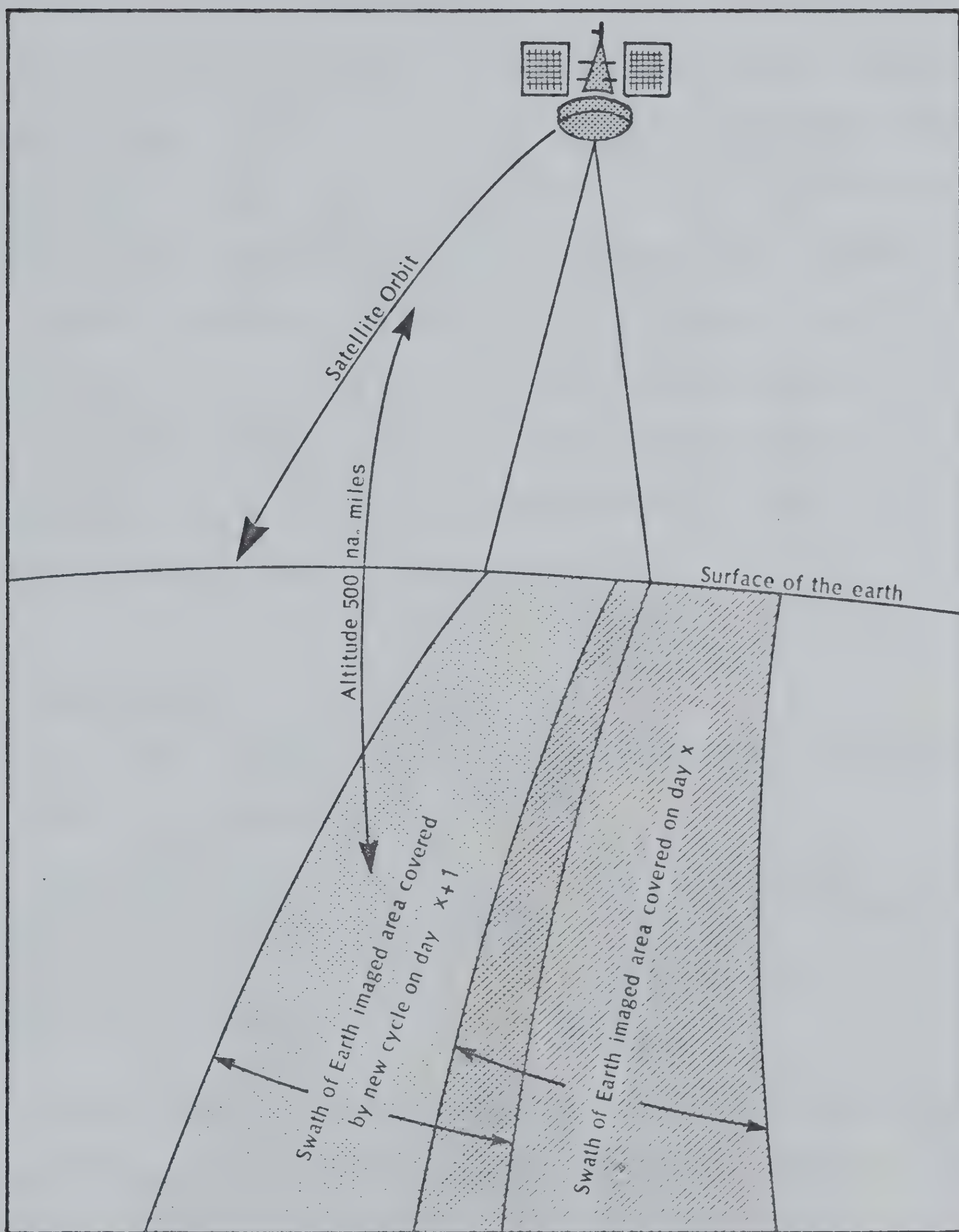


FIGURE 2

COVERAGE OF LANDSAT OVERPASS ON SUCESSIVE DAYS

accomplished by a flat mirror oscillating at $\pm$ 2.89 degrees from nominal with a rate of 13.62 Hz. (NASA, 1972). The along track scan is produced by the forward motion of the spacecraft. The result is data collected in a continuous swath along the ground track at a width of 185 kilometres (Fig. 3). The instantaneous field of each detector covers a square earth area 79 metres on a side (theoretical ultimate resolution?). This area, termed a pixel, actually overlaps adjacent pixels in the same scan line (Malid, Nalepka; 1974). After the data is digitized on board the satellite, it is telemetred back to an earth satellite receiving station. Four stations now exist in North America (Fig. 1) and several have been constructed or are being constructed in localities throughout the world. CCRS is also planning a new receiving station in Eastern Canada.

2.3 Data Products

Data from LANDSAT I and II are available from two government sources in North America:

The EROS Data Center
United States Department of Interior
Geological Survey
Sioux Falls
South Dakota, 57198
U.S.A.

The National Air Photo Library
Department of Energy, Mines and Resources
615 Booth St.
Ottawa
Canada

Two private agencies, General Electric Corp. in the United States and Donald Fischer Associates in Canada, also provide imagery to the public. The government agencies provide LANDSAT data in two basic formats, 7 and 9 track computer compatable tapes (CCT) or photographic paper and film products. All of the MSS data received from the satellite is digital and can be used to produce images using a line printer directly or with the aid of an Electron Beam Image Recorder (EBIR) or a Laser Beam Image Recorder (LBIR) can be

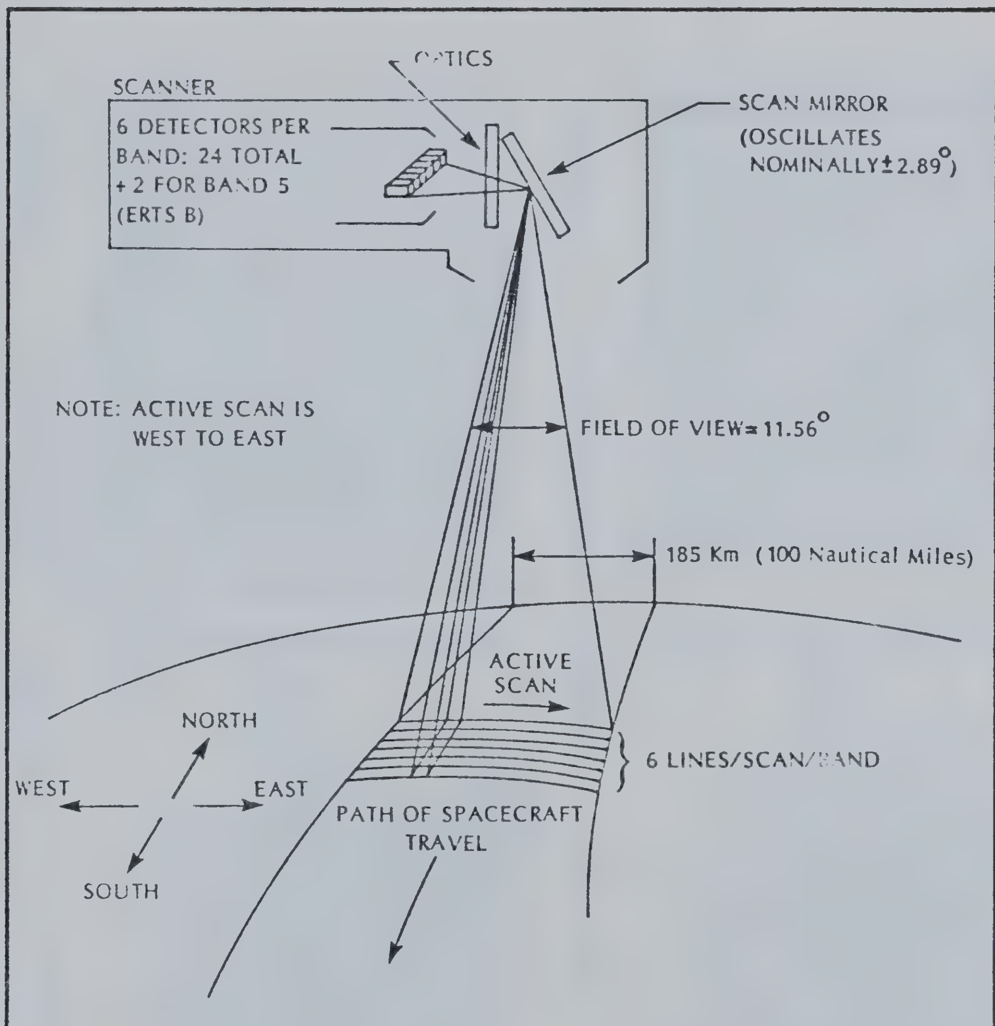


FIGURE 3

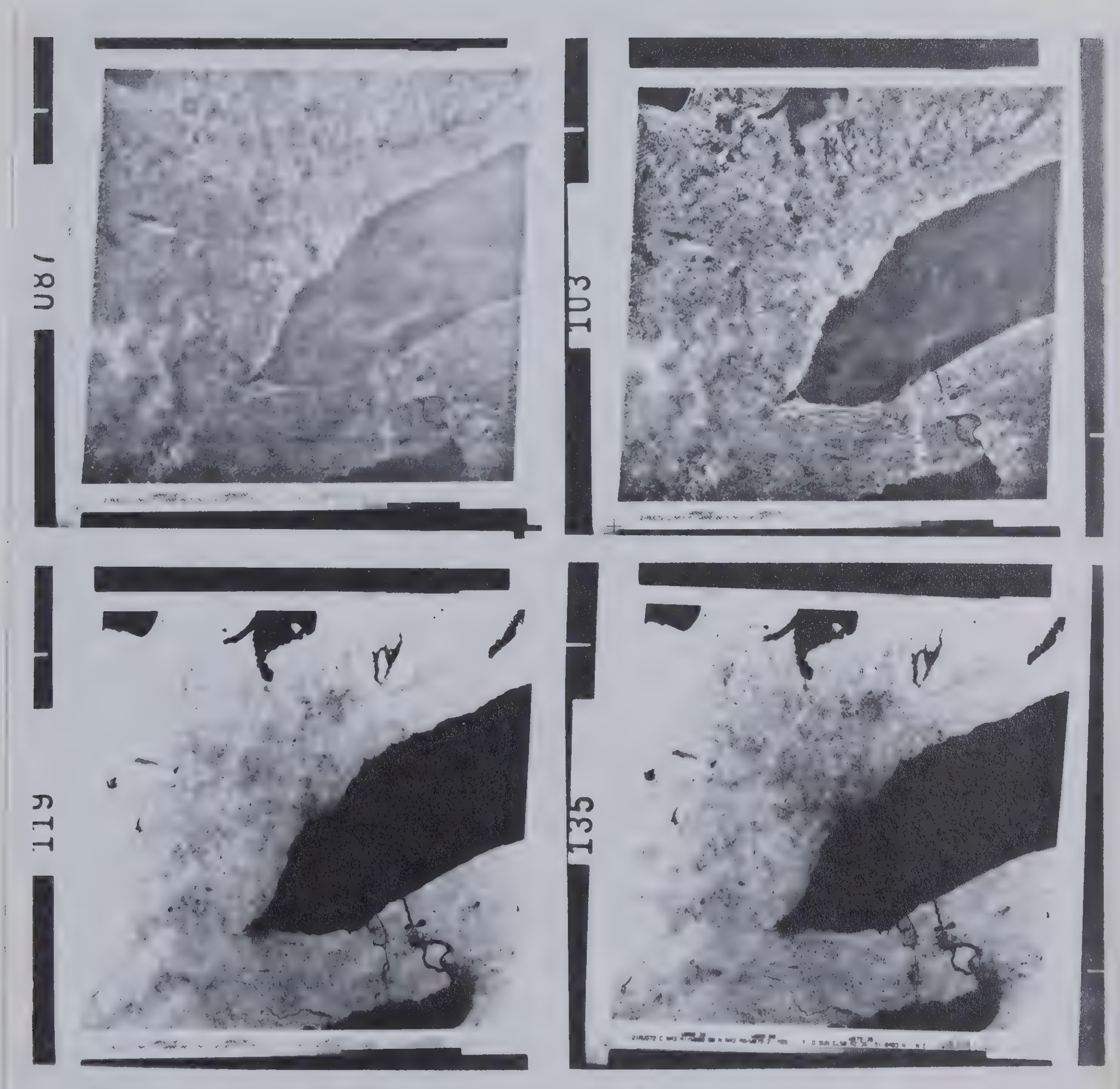
MSS SCANNING ARRANGEMENT

(after NASA, 1972)

FIGURE 4

LANDSAT IMAGE OF TORONTO 21 AUGUST 1972

1029 - 15345



Reproduced by EBIR
Clockwise from top left MSS Bands 4, 5, 7, and 6.

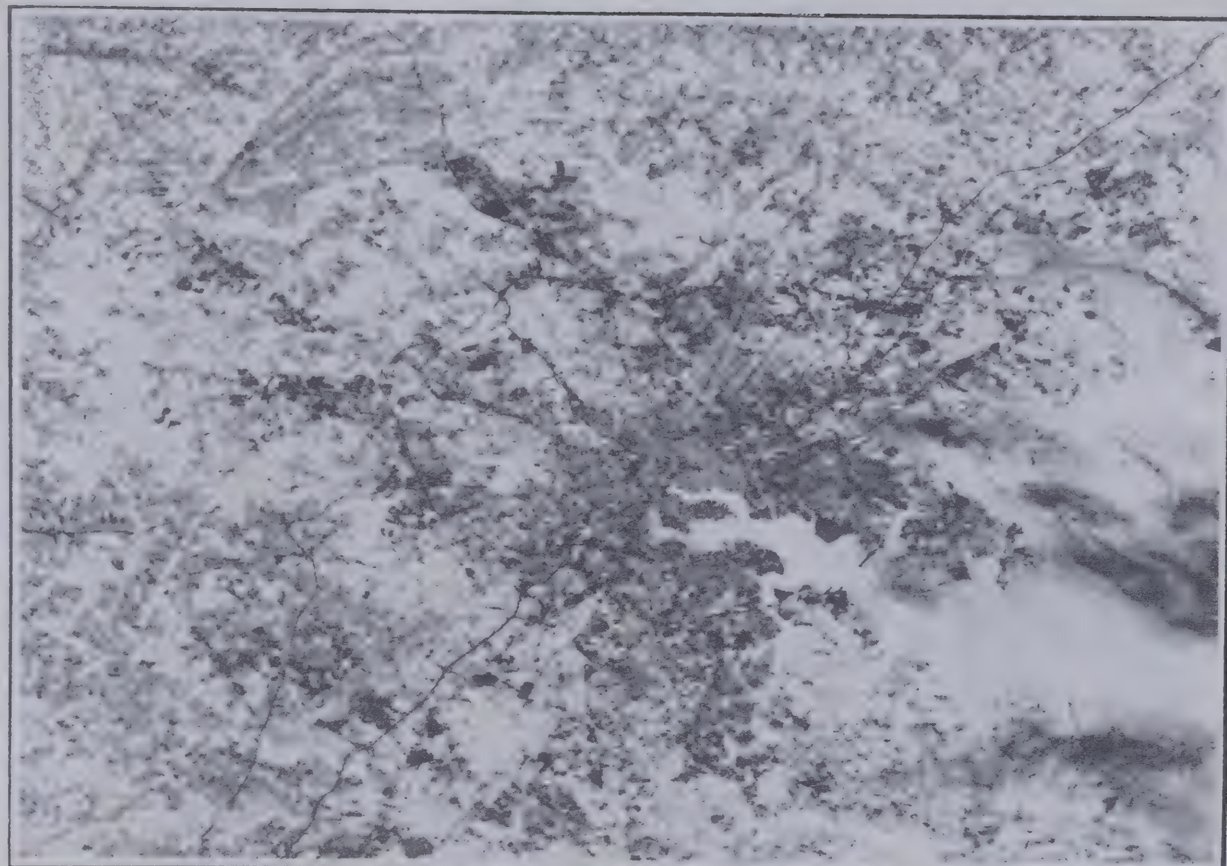
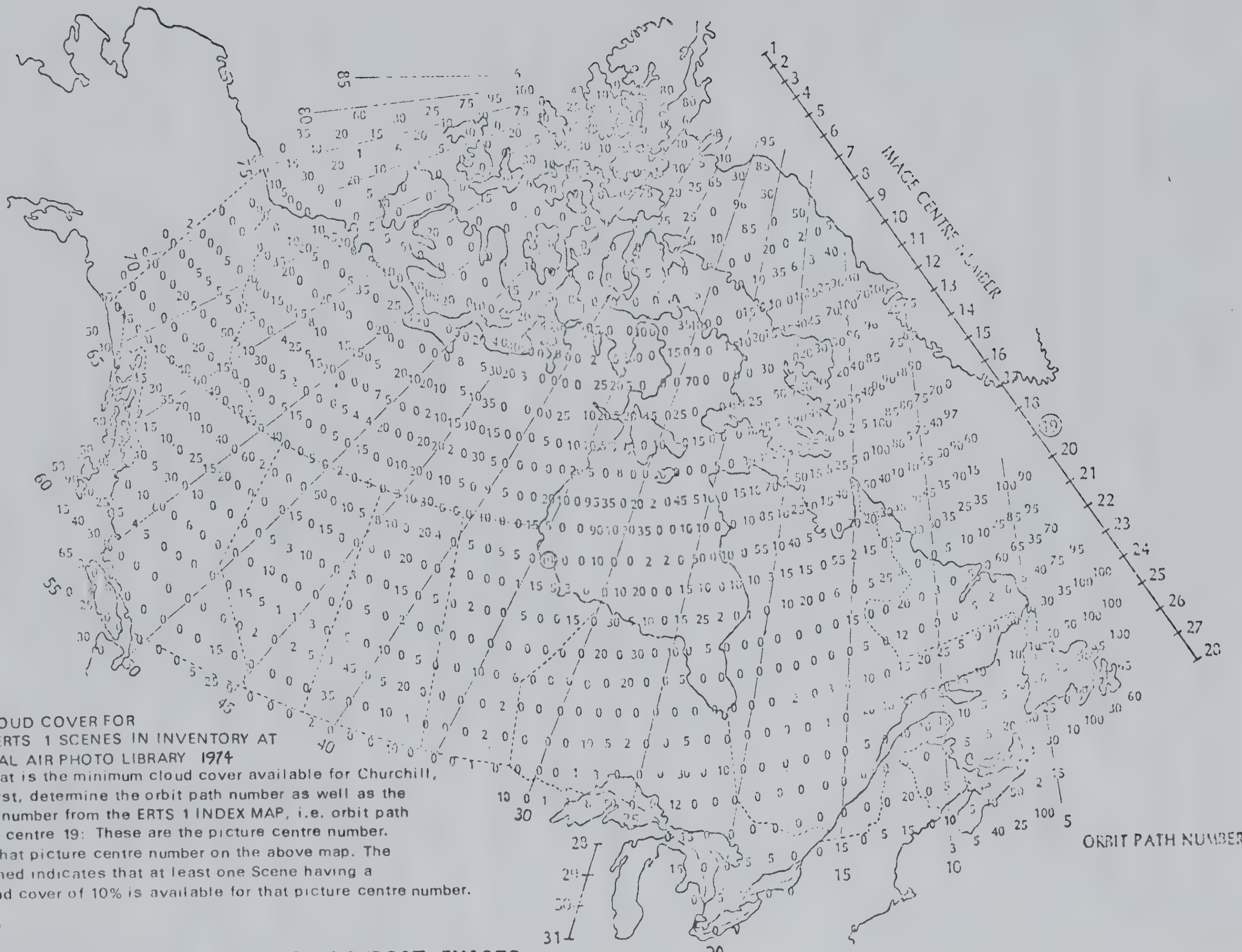


FIGURE 5

CITY OF BALTIMORE IMAGE 1062-15190
(after Rifman, 1973)
Reproduced by line printer, MSS Band 4

converted to photographic images. Both line printer and film writer ultimately offer a resolution down to one pixel. The United States and Canadian systems produce photographic imagery at two basic scales, 1:3,369,000 on 70 mm film and 1:1,000,000 printed on 9.5 inch film or paper. More recently CCRS has undertaken the production of larger film and paper prints up to 40 inches square. These photographic products have system corrections programmed into the imagery data where the computer tapes may or may not be corrected. Any of the four MSS bands can be purchased in computer tape or black and white photographic form. Colour composites of bands 4, 5 and 6 and 4, 5, and 7 are also available in colour photographic form. Examples of imagery from both formats are seen in figure 4 and figure 5 respectively.

The first year of operation produced more than sixty thousand scenes collected by LANDSAT I. All of the United States and Canada and more than 3/4 of all continents have been imaged at least once. As of December 1974 there were over 11,500 scenes in black and white and over 3,250 in colour available for Canada. An index map of LANDSAT I data for Canada locates LANDSAT frames by picture centre number (see map insert - back flap). A cloud cover map (Fig. 6) is also available from CCRS. These two index maps in conjunction with an LANDSAT imagery catalogue greatly facilitate the ordering and collection of usable Canadian imagery. The United States also has a catalogue and index map scheme as well as an open browse file of images on microfilm. More recently CCRS has developed a similar browse file in Ottawa.



MINIMUM CLOUD COVER FOR
CANADIAN ERTS 1 SCENES IN INVENTORY AT
THE NATIONAL AIR PHOTO LIBRARY 1974
EXAMPLE: What is the minimum cloud cover available for Churchill, Manitoba? First, determine the orbit path number as well as the image centre number from the ERTS 1 INDEX MAP, i.e. orbit path 34 and image centre 19: These are the picture centre number. Then locate that picture centre number on the above map. The number obtained indicates that at least one Scene having a minimum cloud cover of 10% is available for that picture centre number.

FIGURE 6

MINIMUM CLOUD COVER ON CANADIAN LANDSAT IMAGES

Scene corrected or precision processed imagery corrected for the Earth's rotation and adjusted to fit a U.T.M. grid is available only for a few select scenes. For the Canadian system "production of precision corrected imagery has been discontinued pending a major upgrading in the stability of the image recorder" (CCRS, 1974). NASA does maintain a facility for precision processing but at considerably greater cost than the standard product. Several private companies also produce precision imagery by specific request (Rifman, 1973) and at considerable cost.

2.4 Geometric Fidelity

Spacecraft attitude and the systematic error of the sensor combine to produce the majority of the planimetric deficiencies within the imagery. Other error sources arise from the configuration of satellite orbit and earth rotation. Algorithms for this later error can be applied to the imagery data on computer compatible tape to produce precision imagery. However, the Canadian and United States systems are only producing imagery on a regular basis which is corrected for the former internal systematic errors. Since the MSS does not have a reseau and preflight calibration data are unavailable, the production of precision processed imagery can be costly and time consuming. Certainly the most desirable image for cartographic purposes would be one with a minimum of planimetric distortion. Keeping in mind economy and the availability of system corrected imagery the question arises; what cartographic uses will the standard format imagery allow?

Bachofer (1973), in his analysis of several LANDSAT scenes produced by the United States system places image centre control to

within one standard deviation or less than six kilometres from the designated nominal centre. This displacement has an offset from nominal to the south and west (Fig. 7). This bias varies for test sites at different latitudes. On recent Canadian imagery this position error has been placed at ten kilometres. He continues his investigations with absolute location, band-to-band registration and temporal registration. These accounts for the MSS operation are summarized in figure 7. Bachofer estimates the relative map accuracy, "... the measure of how well points in an image can be located with respect to other points in that image; that is, it is a measure of how well the internal distortions within the image are corrected" at 120 metres RMS. This value was determined by comparing RBV and MSS images of the same area where it was not possible to seperate error contributed by each system. The composite error was 140 metres RMS.

Other investigators (Colvocoresses, McEwen, 1973) fitted MSS images to ground control points and recorded distortions as large as 1000 metres with the best RMS position error of 233 metres. This appears to correlate with the variation of error recorded by Bachofer. Perhaps the best way to envisage the distortion in MSS system corrected imagery is to plot errors in a portion of an LANDSAT image against a U.T.M. map of the same area as in figure 8.

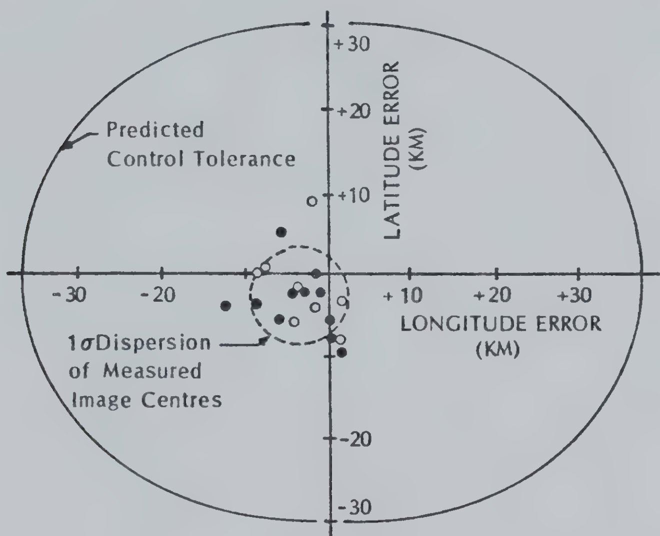
2.5 Resolution

Theoretically, the smallest resolution element detectable by the MSS is 79 metres square, the area covered by the instantaneous field of view of each detector. Pragmatically, with contrast values being generally low the smallest resolved object has been approximately

FIGURE 7

AN ANALYSIS OF LANDSAT GEOMETRIC FIDELITY
(after Bachofer, 1973)

IMAGE CENTRE CONTROL (VARIATION FROM NOMINAL CENTRE)



○ REAL TIME DATA
● RECORDED DATA

LOCATION ACCURACY
(SYSTEM CORRECTED DATA)

2000 - 7000 Metres	LAUNCH THROUGH MID-OCTOBER
1000 - 3000 Metres	MID - OCTOBER THROUGH DECEMBER
500 - 1100 Metres	1973
~800 Metres	PREDICTED

BAND - TO - BAND (SPECTRAL) REGISTRATION (METRES, RMS)

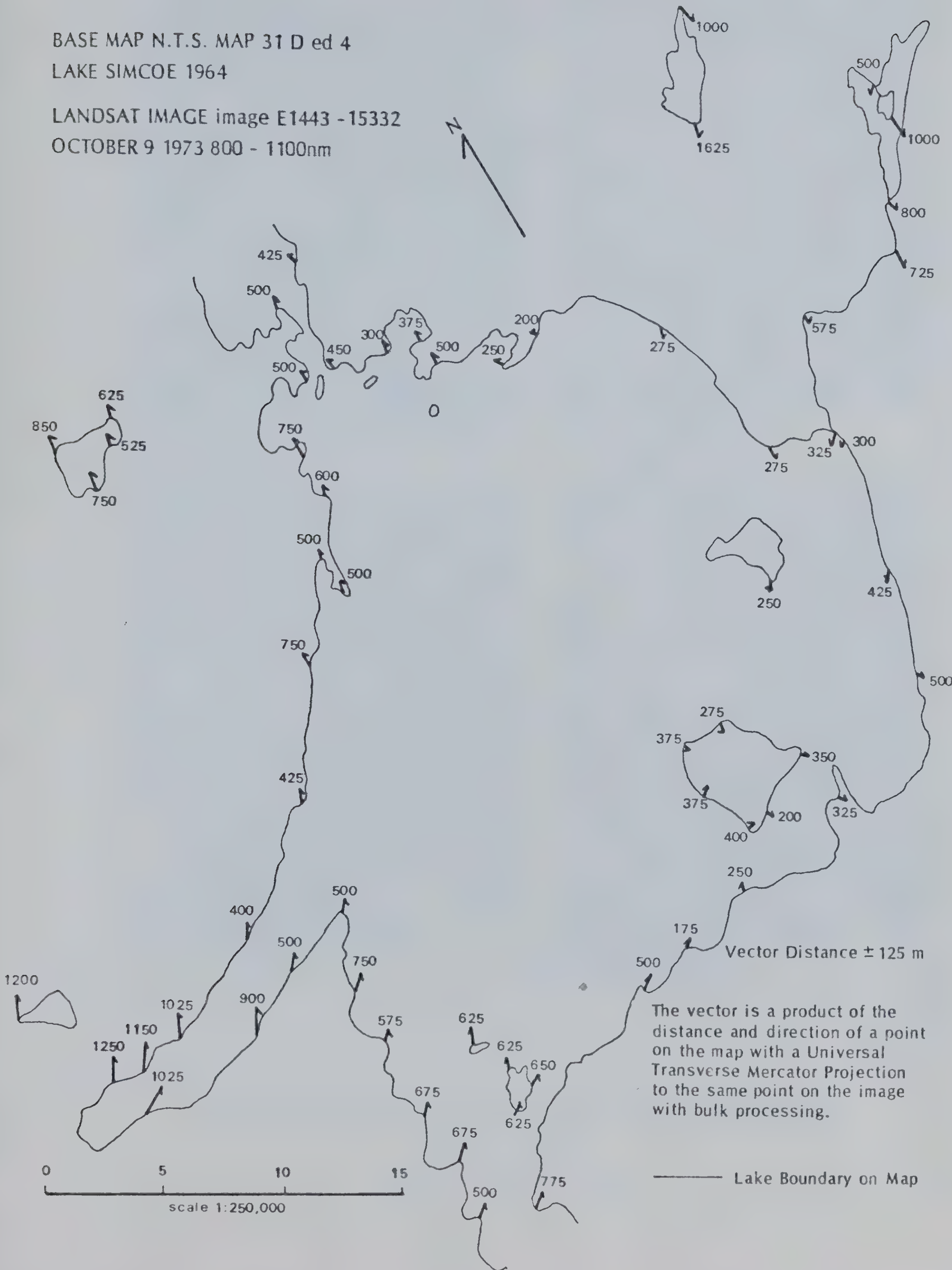
	MEASURED	PREDICTED
MSS	60	159

TEMPORAL REGISTRATION (METRES, RMS)

	MEASURED	PREDICTED
MSS	185	~275

FIGURE 8

RELATIVE POSITION ON AN LANDSAT IMAGE



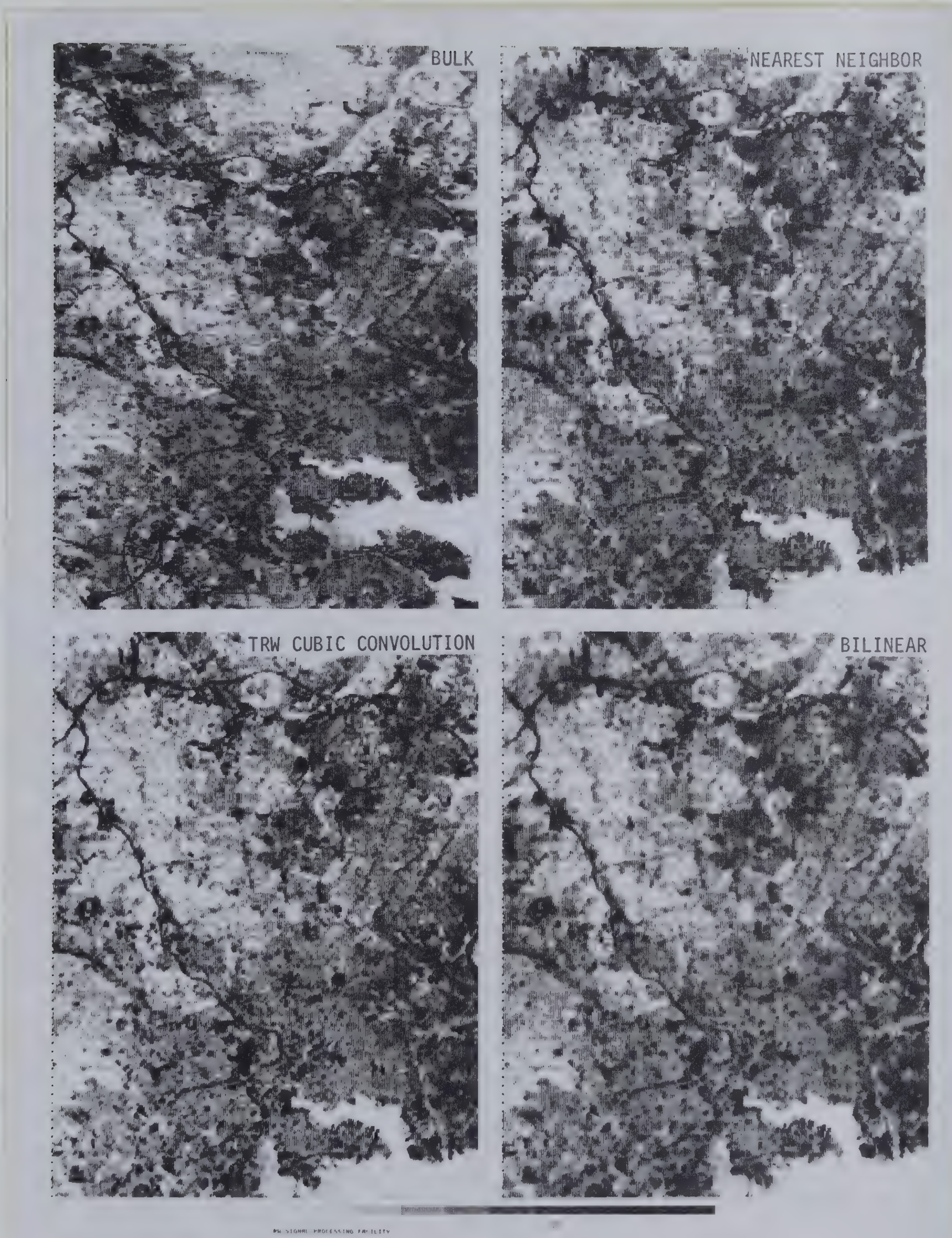


FIGURE 9

THREE METHODS OF PRECISION PROCESSING COMPARED TO BULK IMAGERY
(after Rifman, 1973)

100 metres square with imagery programmed for maximum contrast (photographic products at 1:1,000,000). Without custom programming the resolution values come closer to 200-250 metres (Welch, 1973). Resolution is not necessarily the most adequate concept to use when interpreting regional information. Rosenberg (1971) in discussing detectability and recognizability states that signal (image) can be detected even though it is smaller than the resolution of the system. Anomolies such as this exist with the MSS scanner when it is capable of producing a "signal" for highways which are not as wide as 79 metres. This is evident even in conventional processing as in figure 10 with some of the minor county roads. The LANDSAT system is not a conventional photographic operation; with data in a digital form and the discimination of four frequency bands conventional interpretive techniques may not be enough. For some cartographic purposes the degree of self-generalization provided by LANDSAT imagery can be most useful at this regional scale.

2.6 Cartographic Aspects of LANDSAT Imagery

Some of the advantages and limitations of LANDSAT imagery should now become apparent. Map accuracy standards for United States topographic and related maps dictate that 90 per cent of well defined detail be plotted to within 0.5 mm of its correct position. Converting this to ground distances, planimetric detail must be located within 500 metres (300 metres RMS) at a scale of 1:1,000,000, 250 metres at 1:500,000 and 125 metres at 1:250,000 (150 m RMS and 75 m RMS respectively). Keeping in mind the mapping accuracy of LANDSAT imagery, topographic and similar maps could only be undertaken at scale of less

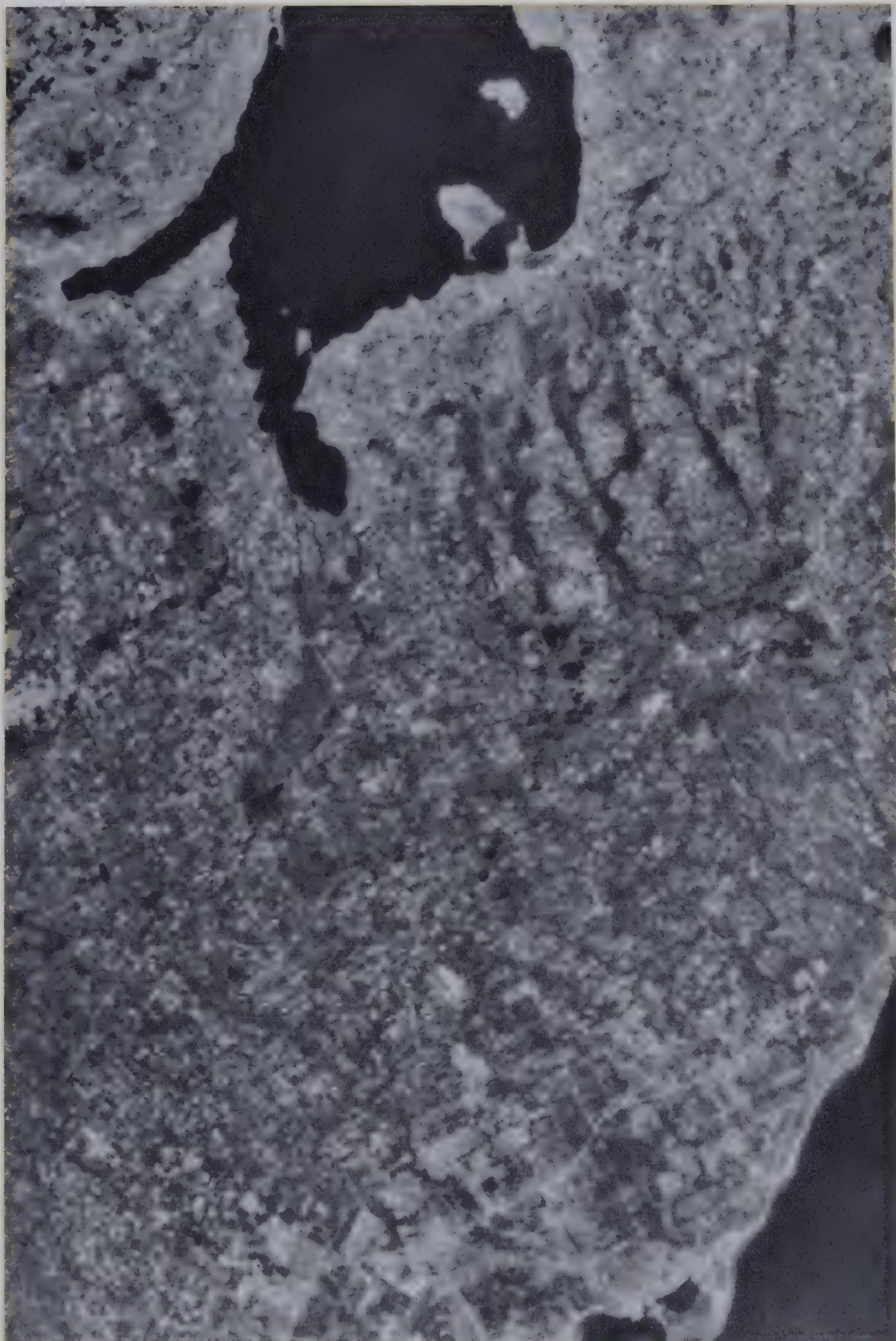


FIGURE 10

A SECTION OF A LANDSAT IMAGE ENLARGED TO 1:500,000

Note the smaller county roads

than 1:500,000. Topographic mapping with LANDSAT is further complicated by the fact that ground resolution values of the 250 metre magnitude (Colvocoresses, 1972; Welch, 1972) limit the mapping capabilities even further and would be compatable only at scales less than 1:500,000. It can, however, be applied to maps other than standard topographic products.[2]

If LANDSAT imagery does not comply with topographic mapping standards, could it be used for mapping thematic topics? Thematic mapping at scales of 1:500,000 and 1:1,000,000 is quite common. Although thematic data plotted on a photographic base are most uncommon, the photographic data have not existed at these scales before. For the first time cartographers have the capability of viewing large regional areas on a single photographic plate. LANDSAT data are regional scale data provided in a time series and allow dynamic as well as static topics to be viewed and recorded (Falconer, 1973). Colvocoresses (1973) in discussing the "Unique Characteristics of ERTS" mentions the near orthogonality of an ERTS (LANDSAT) image:

> "... The field of view of the ERTS MSS extends only 5.67° from the nominal vertical. The near orthogonality of ERTS imagery precludes compilation of topographic (contour) maps but simplifies small-scale planimetric mapping and revision".

These three characteristics (1) the near orthogonality of the imagery, (2) the large areal extent of single images with a relatively homogeneous density gradient, and (3) the availability in a time series should provide an excellent base for correlating abstract

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[2] It should be remembered that these are the regular LANDSAT products, with custom processing to projections such as U.T.M. the locational maximum error of planimetric detail is reduced to 100 m. The resolution goes down to the theoretical maximum of 79 metres (Rifman, 1975).

thematic map data to actual radiometric earth data, producing a thematic LANDSAT map (Adams, Falconer, 1973).

CHAPTER 3

PHOTO MAPPING

3.1 Conventional Orthophoto Mapping

In 1954 the first orthophotographs were developed and cartographers began to evaluate and refine these into new map products. The invention of planimetrically correct aerial photographs made orthophoto mapping a practical proposition. Although photo maps of this type are most useful they have not yet replaced conventional maps but rather have become supplemental maps. The ultimate best use of these "supplemental" maps is still in dispute. Whatever the outcome of such a dispute, orthophoto images offer the cartographer some appealing characteristics as well as disquieting ones.

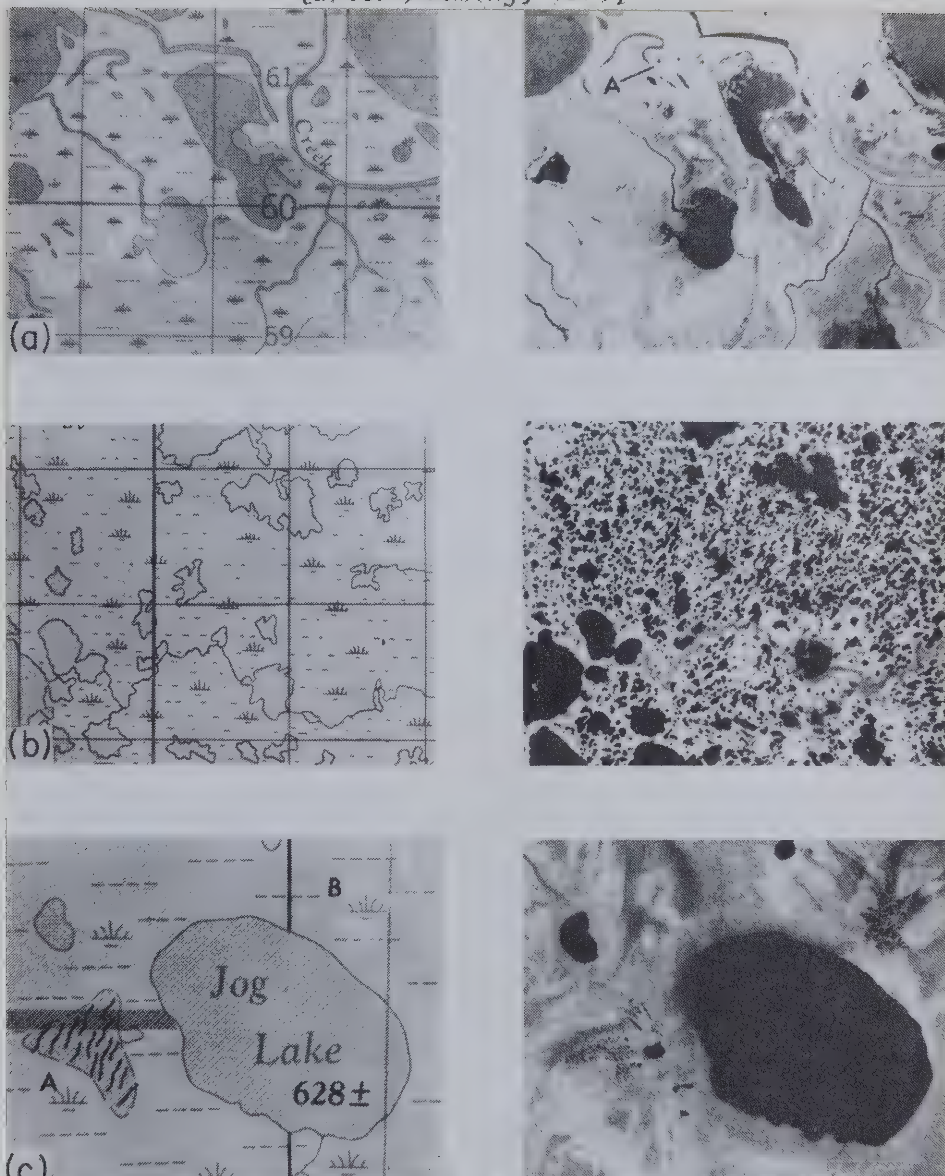
The major dispute is about the value of image content, more precisely photo image content and its counter-part, map image content. The abstract symbology traditionally found on maps is simply inadequate in some instances (Fig. 11). In other mapping situations the photographic detail sets up a "noise"[3] which severely inhibits the interpretation of pertinent map symbology (Fig. 12). Beck (1966 and 1967) summarizes photo map content into three picture categories: (1) planimetry, (2) lettering and conventional symbols and (3) the illustrative picture. The question of how much geographic

---

[3] noise ... any signal, manifested in any form of energy, that occurs irregularly with respect to the signal of interest, and tends to obscure that signal (Cornsweet, 1971).

FIGURE 11

MAP SYMBOLIZATION AND PHOTOGRAPHIC DETAIL
(after Fleming, 1971)



(a) Marsh and swamp (wooded) areas as portrayed by both a line map and a photo detail at 1:50,000. Only the lakes at "A" have not been recorded on the map.
(b) The same marsh symbol as in (a) Now means a multitude of small lakes. The photographic image is able to convey far more information about the terrain.
(c) Two quite different symbols, the string bog symbol at "A" and the marsh symbol at "B" on this 1:250,000 map distinguish between two terrain types that do not differ from each other by as much as those illustrated in (a) and (b).

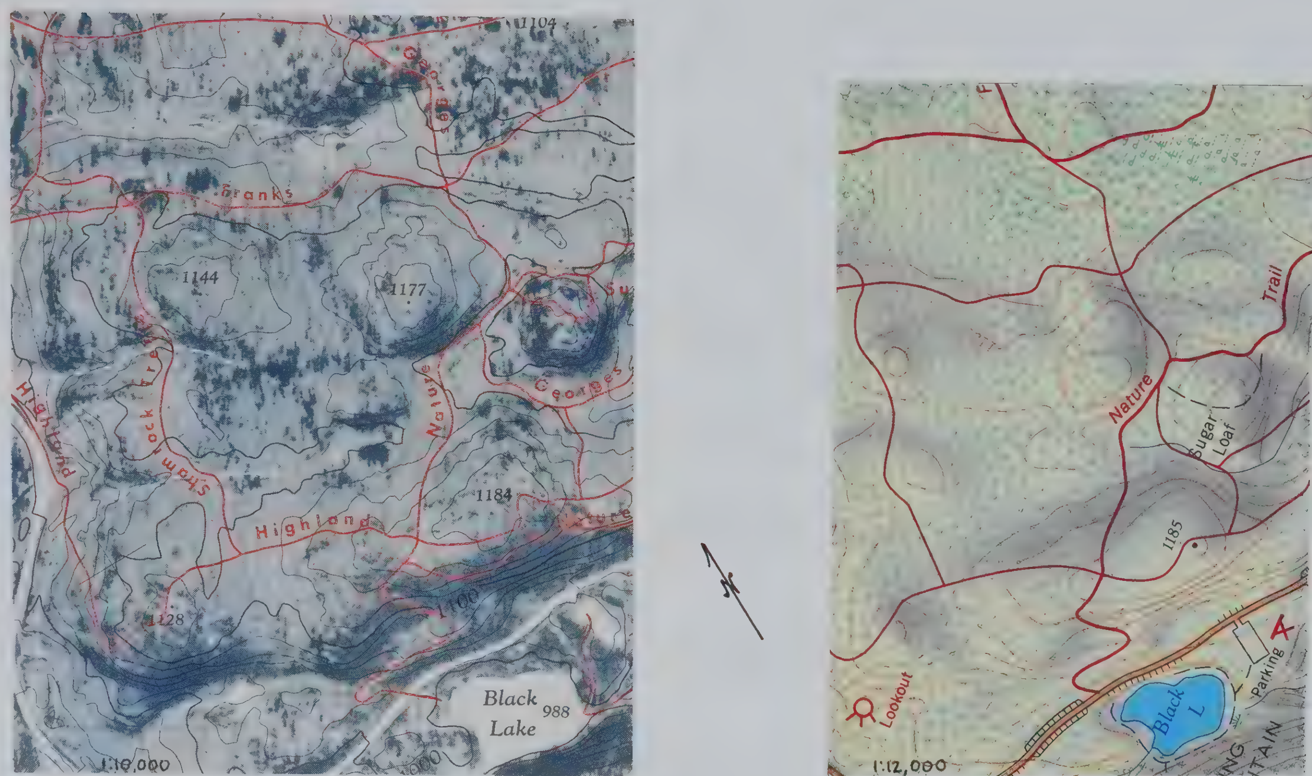


FIGURE 12

A COMPARISON OF A CONVENTIONAL LINE MAP AND ORTHOPHOTO MAP
OF THE GATINEAU PARK AREA

annotation should be added to photo maps becomes difficult when the cartographer realizes that whatever cartographic enhancement is added, the same area of photo image content has been lost or covered up. There is essentially, "no free space available (contrary to a map), so that each supplementation diminishes the content of the picture" (Forstner, 1968). What is an adequate but just representation of photo map symbology? Such a question can only be answered with respect to the intended use and the economic factors surrounding the map production.

Since orthophotographs depend on conventional and wide angle, aerial photography another difficulty with orthophoto mapping arises: the density gradient of the image. The variation in density is attributed to the altitude/azimuth of the sun and the fall off in illumination through the camera lens (Fig. 13). Serious problems develop when combining different images to form a photo mosaic or in this case an orthophoto plan. Tonal mismatches on adjacent flightlines and prints can be reduced but not always eliminated (Fleming, 1971). This becomes of particular interest when photo mapping is undertaken at scales smaller than those achievable through single aerial photographs. In fact, Beck (1966 and 1967) feels that the problem of orthophoto mapping at scales of 1:1,000,000 and less cannot be solved satisfactorily and that, "The orthophoto of medium and smaller scales (without transformation of its picture) in general has no chance to act directly as a modified map depiction", "... Although aerial photographs taken from artificial earth satellites are already used for several important purposes" (Forstner, 1968).

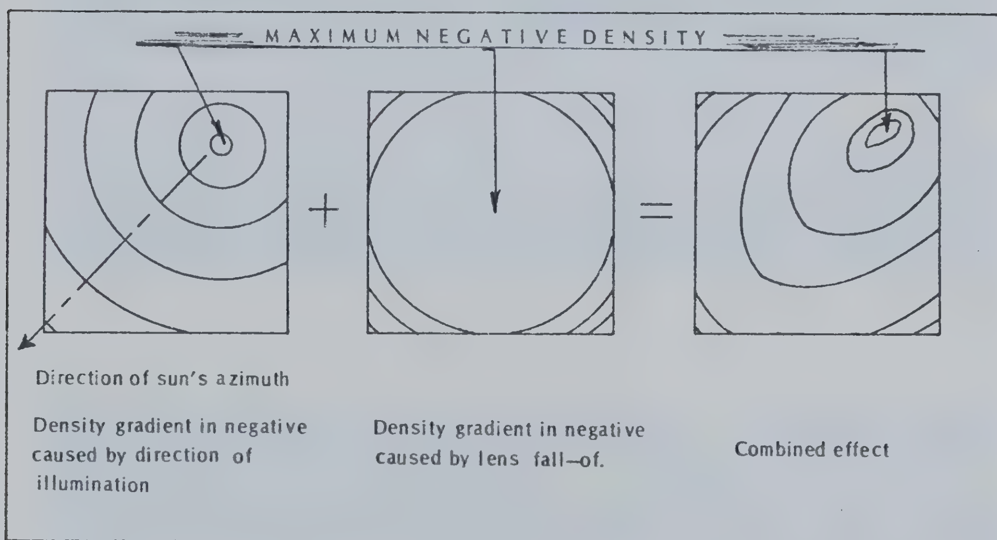


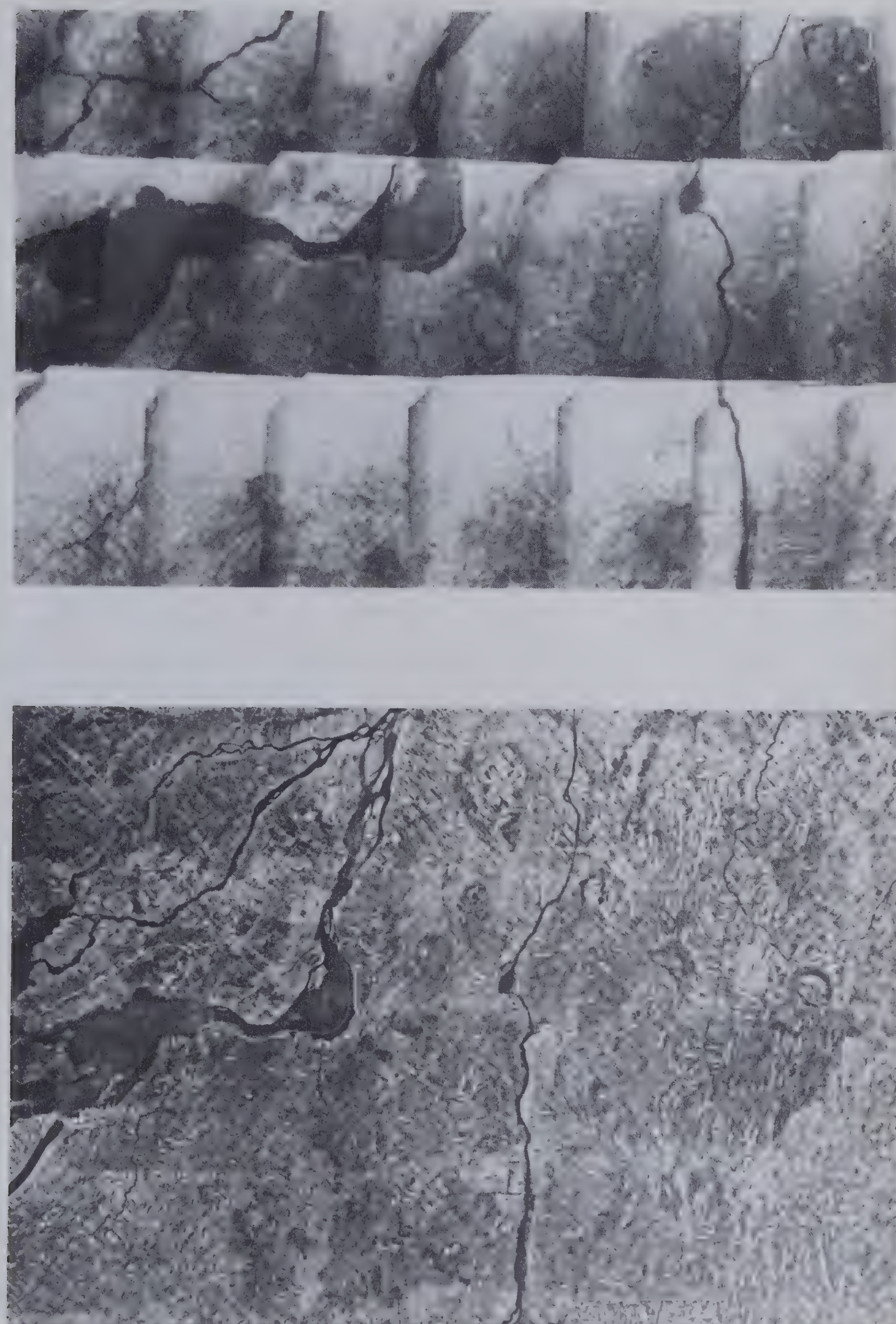
FIGURE 13

DENSITY DISTRIBUTION ON AN AERIAL PHOTO NEGATIVE

(after Fleming, 1970)

FIGURE 14

PHOTO MOSAICS OF MONTREAL UNDODGED AND AUTODODGED PRINTS
(after Fleming, 1970)



In any respect if orthophoto maps are to become functional at all scales more interpretation of the photo image will be needed by the map user. This may put greater stress upon an educational system that teaches photo interpretation techniques as well as map interpretation techniques (Hardy, Rolland, Taranik, 1973), but the long term benefits should be rewarding. When the user becomes able to decipher the wealth of detail in the photo and correlate that information to the more symbolic map information a positive step towards more objective mapping will be made. Maybe this is easier than it sounds.

> "Fortunately, interpretation of the photographic image does not present serious difficulties, and it is our experience that persons, such as farmers, not accustomed to using maps, have less difficulty in reading the photographic image of the earth." (Blachut, 1968).

3.2 LANDSAT Orthophoto Mapping

With the initiation of the LANDSAT program some of the limitations of conventional orthophoto mapping should now be reviewed. LANDSAT imagery, although not universally suited to mapping at scales greater than 1:250,000, provides an adequate base image for mapping the "smaller" scales (i.e. 1:1,000,000) mentioned by Beck. The imagery system of LANDSAT being a scanning apparatus is more able to produce a relatively uniform density gradient. Radiometric infidelities exist but at comparatively lower levels than those experienced by conventional aerial photography. The necessity of combining several photographic images, of different tonal values, is reduced if not eliminated in some cases. Falconer (1973), when discussing LANDSAT imagery, has stated that "the tone of the print is such that for many inter-

pretation purposes it may be considered to be the ideal mosaic." At these smaller scales with emphasis on the macro features of the landscape the self generalizing effect of LANDSAT image resolution is not as problematic as it would be at the larger scales of conventional orthophotography. LANDSAT imagery provides a new area for mapping endeavors previously not possible with traditional methods.

3.3 The Economics of LANDSAT Photo Mapping

In 1970 the Surveys and Mapping Branch of the Department of Energy, Mines and Resources produced three experimental photomaps at a scale of 1:250,000: 31H Montreal Sheet, 52L Churchill Street, and 85 NE Yellowknife Sheet. These photo maps were developed from orthophoto plans derived from many orthophotographs obtained by high altitude aircraft. Figure 14 illustrates the variation of density gradient within an undodged mosaic as compared with an auto-dodged mosaic for a portion of the Montreal sheet. The Montreal Sheet production needed 108 super-wide angle, aerial photographs at an average photo scale of 1:107,000. The final photo map scale was 1:250,000. Three separate flights were finally undertaken to collect suitable photography. The rectification and mosaic time along for the images was approximately 30 hours (Fleming, 1970). It was concluded that a suitable photomap could be produced but that error in interpretation by the user could result if he forgets that the individual images were dodged to produce a uniform appearance of the final map.

If the same area were to be covered by LANDSAT I imagery it would require 5 images on 3 paths. This would be needed to obtain cloud free coverage. Only 4 out of 84 orbits produced useful imagery in

this respect "thus on the basis of obtaining cloud-free coverage of a specific area, ERTS is no quicker than aerial survey ..." (Stewart, Fleming, 1973). This problem should be further reduced with the introduction of LANDSAT II imagery. As with any mapping project the ultimate decision about imagery will be based on factors such as scale, specific purpose, timing, etc. However, considerable advantage is gained by having to dodge only 5 prints, if any, and since coverage now exists for most of Canada the production of photo maps at small to medium scales should cost very little, in both time and money. An LANDSAT print as in figure 15, at a scale of 1:1,000,000 for a single band costs only 2 dollars.

3.4 Nation's Capital Area ERTS (LANDSAT) Map

The Geological Survey of the United States Department of Interior with assistance from the National Areonautics and Space Administration published the first map using a LANDSAT image as a mapping base early in 1973. The map covers the Baltimore, Washington D.C. areas and includes portions of the Potomac River and Chesapeake Bay. This LANDSAT map was produced at a scale of 1:250,000 with an image size of 29 inches by 28 inches. The map was printed on 100 pound enamel coated stock with overall trimmed dimensions of 33 inches by 31 3/4 inches. The satellite image is reproduced to simulate colour infrared photography corresponding to standard colour composite processing by NASA. The map was printed at the 1:250,000 scale with 150 lines per inch screens using process colour. Positive images of MSS bands 4, 5, and 7, were utilized when band 4 was printed in yellow, band 5 in magenta, band 7 in cyan with black reserved for cartographic

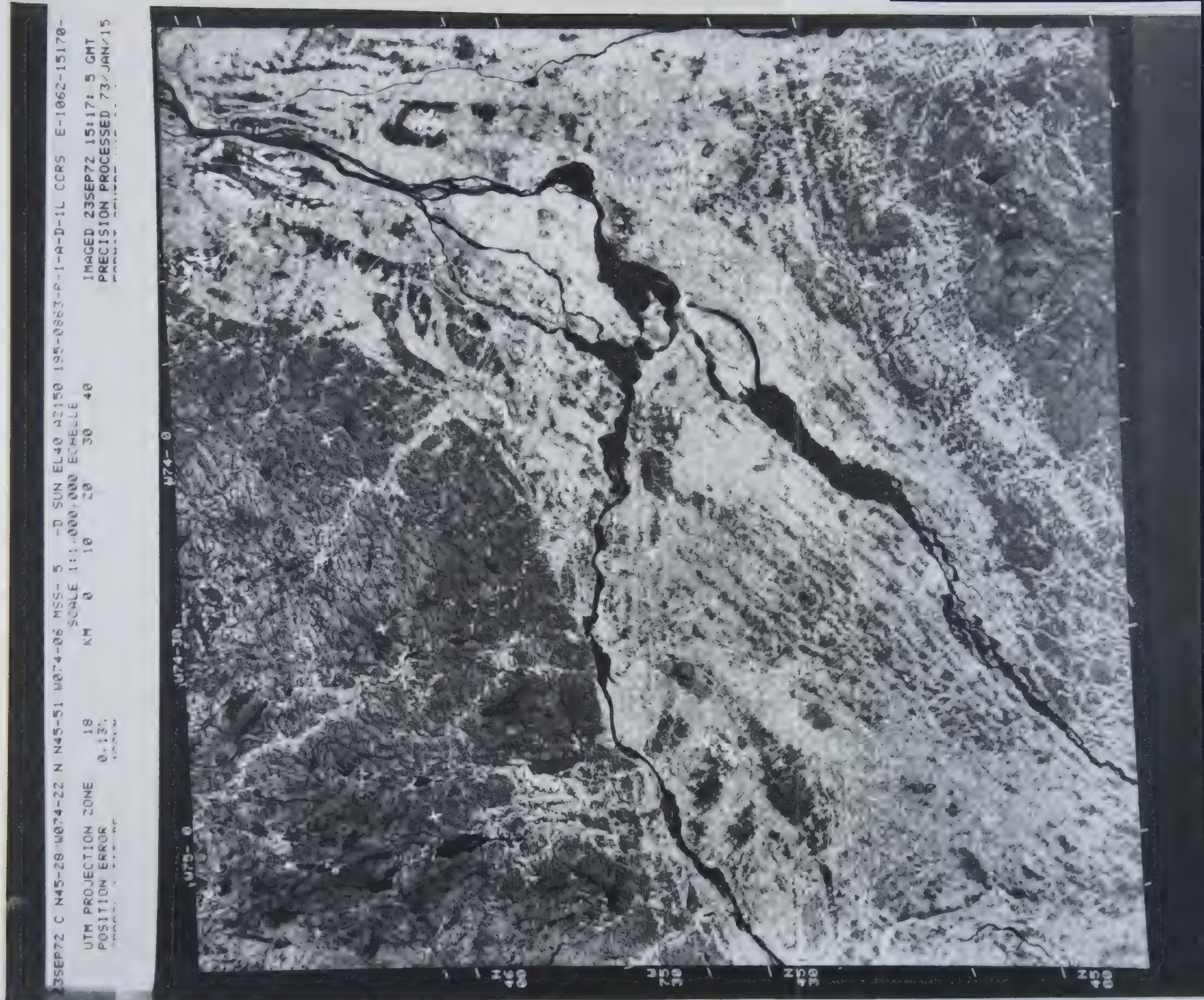


FIGURE 15

A LANDSAT PRINT OF THE MONTREAL AREA

1062 - 15170

symbology and type. The map and print of the LANDSAT image without enhancement at the same scale was distributed at the Second Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, March 5-9, 1973. Sections of the map and the accompanying LANDSAT image print are illustrated in figures 16 and 17 respectively.

The cartographic annotation uses open symbols for both point and line representation whenever possible. In other cases they are held to minimum size. Apart from the symbol used for mud and sand, no areal symbology exists other than delineation by a surrounding border line and what can be interpreted from the imagery - forested areas, built up urban areas, etc. The only relief representation offered by the annotation is the use of spot elevations on land and generalized 30 foot contours for hydorographic relief. The boundary of land and water delineated only by the image but the names of major mountains are included as additional locators. Point symbols are used to indicate power plants, storage tanks, churches, schools, mines, towers, beacon lights, small communities, small airports, and seaplane bases; in essence they are the standard symbols used on conventional 1:250,000 topographic maps. The line symbology maintains the same topographic set of symbols showing highways, multiple to single lane with highway numbers on open shields; railway lines, multiple or single track; state, district, city, and reserve boundaries; power transmission lines are also indicated with a line symbol. In some cases these line symbols are incomplete such as along river channels and in spots that would be delineated by additional printed colours on standard topographic maps of this scale. Such inconsistencies indicate that the black symbology for the U.S.G.S. 1:250,000 topographic map series was overprinted on an LANDSAT image base. Perhaps this use of

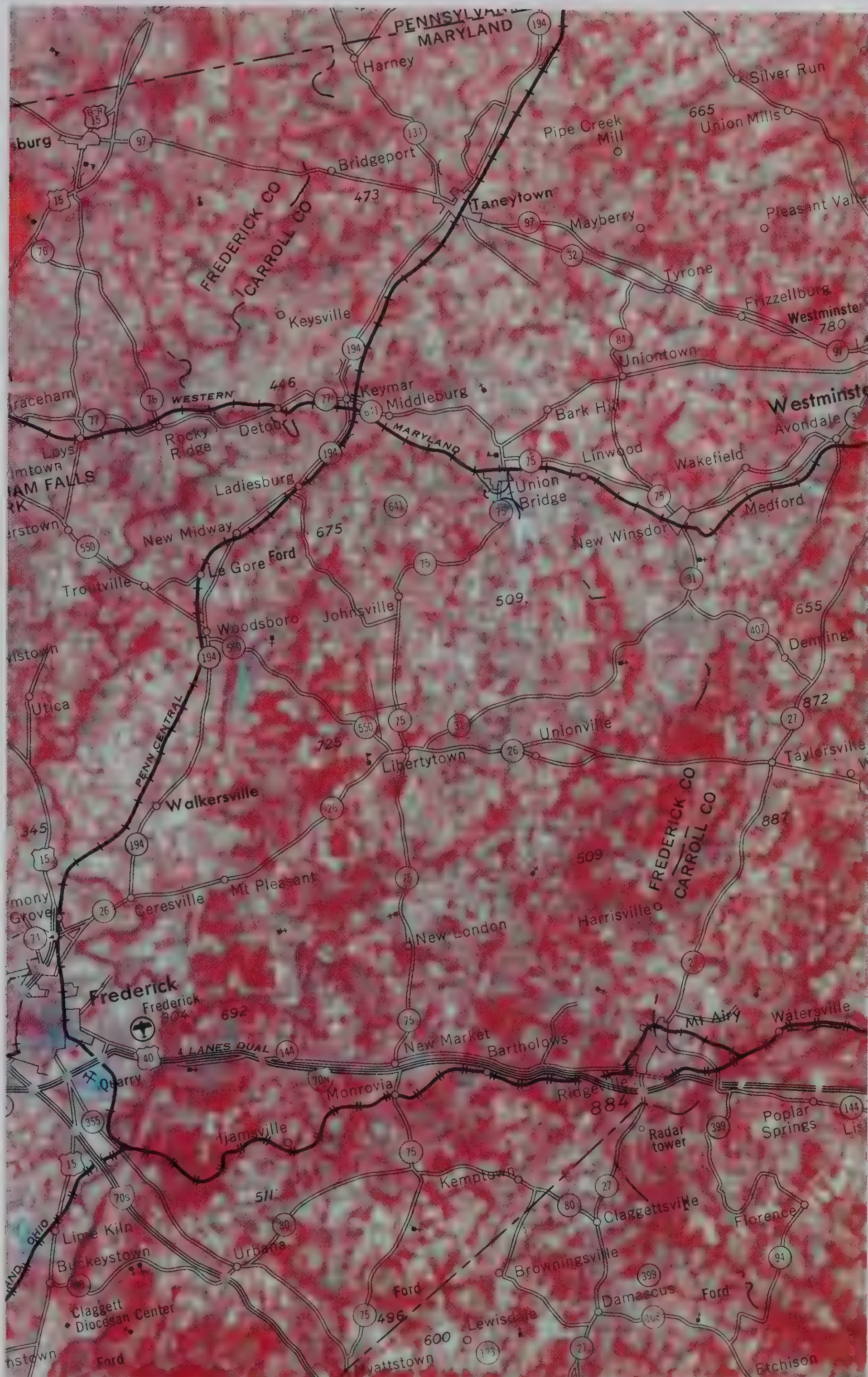


FIGURE 16

A SECTION OF THE WASHINGTON D.C. ERTS (LANDSAT) MAP

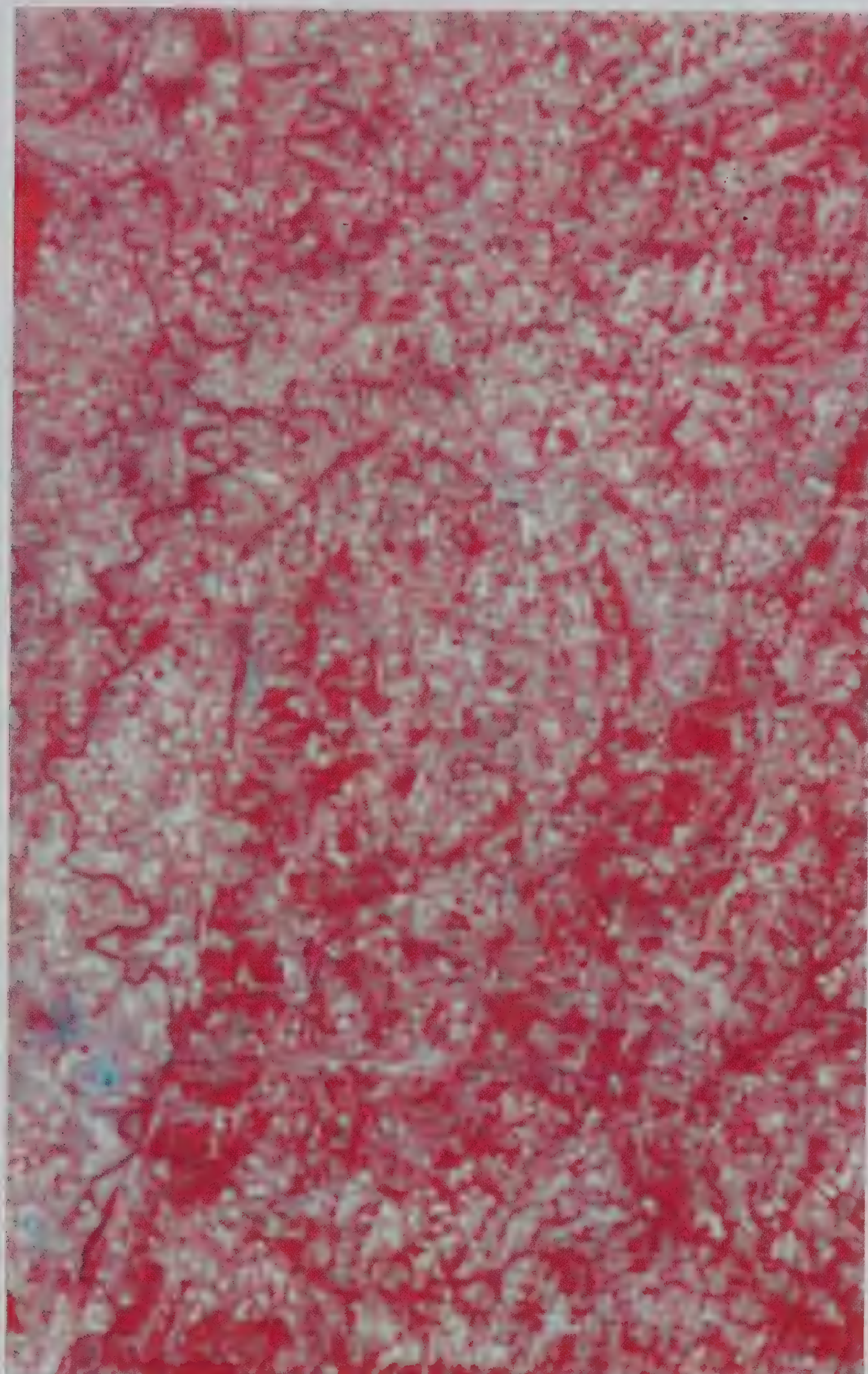


FIGURE 17

A SECTION OF THE ERTS IMAGE DISTRIBUTED WITH THE WASHINGTON D.C. ERTS (LANDSAT) MAP

standard topographic symbols is enough justification for the conspicuous lack of legend and explanatory information. A representative fraction with miles and kilometres bar scales are included, however. External grid reference indicators differ from those used on the topographic map series while the internal tick marks remain the same. The only external grid markings are two longitudes and one latitude similar to those found on the LANDSAT image. A north arrow does exist in the lower right corner. Type for the map is also the same as that used on the black printing plate of topographic series: principally variations of Roman and Gothic styles with serif and sanserif, upright and italic, using both upper and lower cases.

The map is basically a general reference map relying heavily on type written information and the fundamental symbol map[4] representation. The compilation time was held to a minimum by combining the LANDSAT image with a standard topographic overprint. The cartographic information is clear and easily read and the image information offers the map user an abundance of data not available in conventional maps of this type. A prime example of such user interpreted information is the easily seen areal extent of concentrated sediment load in the Potomac River. The only real drawback to the image is a certain fuzziness indicative of image processing at the time of publication. Since that time films have been developed which will reproduce 45 lines per mm (Falconer, 1974) and should help to reduce this problem in the future. In any case, 1:250,000 does seem to be the maximum enlargement

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[4] Although all maps have symbols, the "symbol map" referred to here is a qualitative representation where "data are presented in the form of a specific symbol which can be of a pictorial, geometrical, evocative or alphanumerical design." (Klawe, 1973; Ratajski; 1963).

permitted by the standard LANDSAT image product. Although this deficiency exists, the combination of user interpreted LANDSAT image and conventional map symbology has produced a distinctive and effective map product.

3.5 The National Capital Region - Experimental Photo Map

Another LANDSAT map has been produced by the Canada Centre for Remote Sensing. This map is centred on the Ottawa-Hull region and includes 10,000 square kilometres of surrounding area. It is printed at a scale of 1:250,000 and covers portions of the NTS series maps 31F and 31G. The map is printed on 100 lb. enamel coated stock with trimmed dimensions of 31 inches by 23 inches and a printed map image size of 16 3/4 by 17 1/2 inches. A short explanation of the satellite sensors including the colours in which the spectral bands are printed and a rudimentary interpretation guide are printed beside the map image in both English and French. The Ottawa LANDSAT map was distributed after the Second Canadian Symposium on Remote Sensing in mid 1974 and may be obtained through CCRS, Ottawa.

The Ottawa LANDSAT map like the Washington D.C. map was printed to simulate a colour infra-red aerial photograph. Simulated colour infra-red processing is also a standard medium for CCRS colour composite imagery. The LANDSAT image is printed with 150 line screens and again uses process colour printing. Unlike the Washington map each of the spectral bands used, is printed in two colours: band 4 represented by blue on the map is printed in magenta and cyan, band 5 uses cyan and yellow to produce green, and band 7 is printed in yellow and magenta to produce a red colour on the map image. The effect attained is a strikingly sharp and clear image;

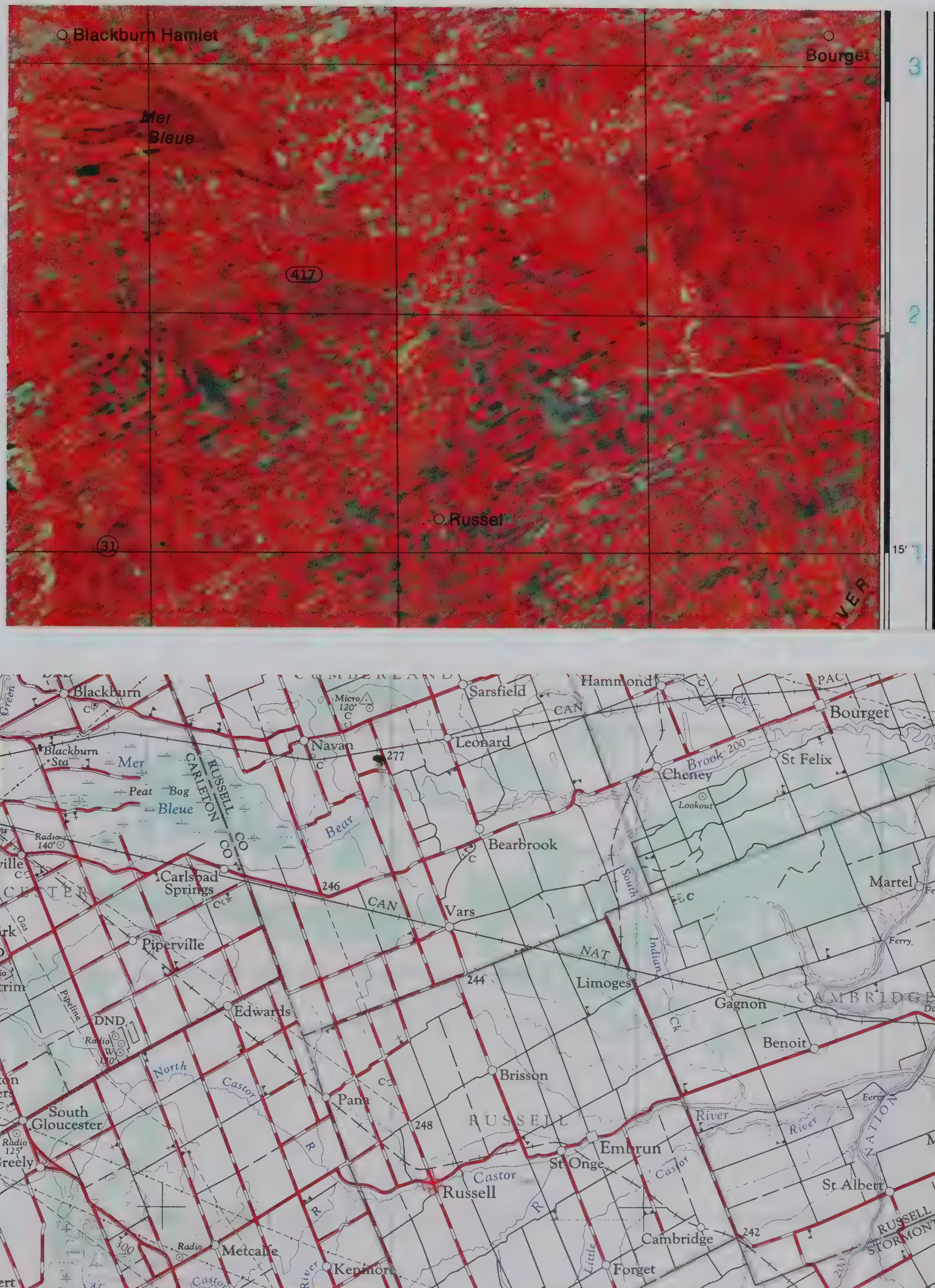

FIGURE 18

A SECTION OF THE OTTAWA LANDSAT MAP AND THE CORRESPONDING N.T.S. TOPOGRAPHIC MAP

one which could be easily interpreted by the map user.

The symbology for the map is held to an absolute minimum. Only four point symbols in conjunction with type are used to represent all features on the map. They designate towns, highways, airports and quarries. All symbols are open symbols and allow the under image to be seen. Type appears in both black and a cameo or white form, the latter being used on some hydrographic features such as the Ottawa River. All type is sanserif and in a style similar to Univers. Upper and lower case as well as an italic are used. Type is used in many cases to delineate linear and areal features such as power lines, railway lines and city areas like Ottawa. Scale is illustrated by a representative fraction and by mile and kilometre graphic scales. Only a section of the original LANDSAT image has been utilized, however, it has been trimmed and oriented with North at the top. This allows the standard NTS borders and grid systems to be employed. They include a ten thousand metre Universal Transverse Mercator grid and a longitude/latitude grid with fifteen minute markings. Legend, titles, and scales are also written in English and French. No indication of relief is represented. Examples of sections of the Ottawa LANDSAT map and the corresponding N.T.S. map are given in figure 18.

Perhaps the greatest difference between the Ottawa and Washington D.C. LANDSAT maps is in the conceptual design. The Ottawa map relies almost entirely on interpretation of the LANDSAT image to convey information. Map symbology is very sparse, consequently it produces the impression of a annotated photograph rather than a map or photo map. Any additional information needs to be derived from the corresponding N.T.S. 1:250,000 map sheets, 31F and 31G, however, these sheet

numbers are well noted on the map. The map was distributed alone, so one wonders if it is to stand alone. The Washington D.C. map, on the other hand uses map symbology liberally, compared to the Ottawa map but it was distributed with an LANDSAT image print completely lacking in symbology. The image quality of the Ottawa LANDSAT map is exceedingly better than the "fuzzy" Washington image but the lack of map information gives it an unfinished look. The problem arises once again - how much map information should be added to a photo map? Perhaps the question, "What information should be added to a photo map?" should also be considered. Both agencies, CCRS and NASA, seem reluctant to have the LANDSAT map stand on its own for this type of "symbol" representation.

CHAPTER 4

THE TORONTO CENTRED REGION MAP

4.1 Introduction

The ERTS (LANDSAT) map of the Toronto Centred Region was conceived, initiated, and designed as an experimental project by the map authors.[5] The nature of the experimental map was intended to capitalize on the compromises made during production to evaluate the primary objectives and publish the results at the Second Canadian Symposium on Remote Sensing, in Guelph, on May 1, 1974. The primary objectives were:

1) to produce a LANDSAT map, basically general reference, but developing a more thematic content (i.e. an "areal extent" component) emphasizing a suitable combination of map symbology and image symbology;

2) to manipulate the hues and saturations of the MSS spectral signatures in reproduction to help develop a more natural appearing landscape with elements approximating hypsometric tints;

3) to evaluate the use of a LANDSAT image as a thematic cartographic base;

4) and to stimulate potential and future investigations of LANDSAT mapping in which the LANDSAT image is used directly as a mapping base.

The authors also felt an additional responsibility to construct the LANDSAT map at its maximum allowable scale, 1:250,000 and examine this scale of imagery for mapping. This not only facilitated a greater

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5 The design and production of this map was coordinated by Dr. Allan Falconer and Fred Adams in association with the Department of Geography, University of Guelph.

image area to symbol area ratio, but also provided a mechanism for evaluation of the more thematic elements at this larger scale. Comparison between this map sheet and the Washington D.C. and Ottawa LANDSAT maps would be facilitated if all were produced at the same scale. Although mapping at this larger scale was initially considered an asset, disadvantages came to light when further constraints were placed on the imagery.

4.2 Mapping Constraints

Imagery and map specifications needed to be established before any preliminary mapping endeavors could begin. Map requirements dictated the Toronto Centred Region as the area to be mapped. This was due primarily to the need of the map to be correlated with an existing on-going project in this Great Lakes area. Other factors lending additional weight to this decision were; the availability of extensive data for the region, the diversity of cultural and physical characteristics of the area, and the market potential within the region if the map was to ultimately become a commercial endeavor (dictated by funding sources). These mapping constraints directly controlled the specifications for a suitable image and were considered simultaneously with imagery requirements. The imagery needed to have been centred on Metropolitan Toronto and cloud free, or nearly so. Secondly the imagery should have been of highest definition permitting enlargement to final map scale. Thirdly the imagery should have been precision processed to maintain map accuracy requirements.

A review of available imagery in conjunction with the mapping objectives and limitations required compromises to be made. The decision to map the region using the 21 August 1972 NASA scene was made because it was the sole single image available. More recent CCRS imagery which was better in resolution quality existed, however, this LANDSAT pass was split into two images by standard CCRS processing and equipment for reprocessing was not available. Consequently, the decision to use lower resolution imagery maintaining Metropolitan Toronto at or near the centre of the image was established. A further compromise was made regarding precision processing due to the complete lack of available imagery from the CCRS or NASA systems. Both of these problems can be overcome for future LANDSAT mapping but could not be controlled by the map authors, and since the primary objectives of the map were design oriented, compromises were made.

Apart from the theoretical limitations there were some administrative ones directly associated with limitations of equipment and co-operating agencies. The end result was a map physically produced at three organizations; the University of Guelph for compilation, Lockwood Survey Corporation for scribing, and Graphic Litho Plate for all photography, registration and plate making. Time constraints were severe considering the administrative intricacies of the three organizations plus those of York Litho Company, the printers. The compilation started in mid-December of 1973 and the map was to be off the presses in mid-April, 1974 just before the 2nd Canadian Remote Sensing Symposium.

4.3 Compilation and Design

The production of the Toronto ERTS (LANDSAT) map actually began sometime before its compilation, with the construction of two sketch maps using photo prints of a LANDSAT colour composite as a base. Since so few LANDSAT maps existed at that time a greater insight of the LANDSAT map design was needed. These preliminary maps helped to achieve this. They were compiled at the standard LANDSAT format scale of 1:1,000,000 on a simulated infrared image using bands 5 and 7 of the 21 August 1972 NASA scene. One preliminary map had monochrome black symbology while the other utilized red, yellow, blue, and black. A print of the latter sketch map appears in Figure 19. The most striking initial impression was that the symbology covered too much of the image detail.

Concurrently, investigation proceeded on the image itself. Due to the inherent characteristics of the MSS, any image produced from the system is essentially a false colour image. This image could have simulated a more natural landscape as easily as it could have simulated an infrared photograph. At this time NASA and CCRS also started producing an alternative image to the simulated IR image which approached the desired colour combination for the map. However, the map authors believed that more experimentation was needed. Through the media of diazo colour composites the different LANDSAT bands were manipulated producing combinations that more closely simulated a natural landscape. Examples of a NASA simulation and a Diazo colour composite appear as prints in Figure 20. Experimentation with both positive and negative colour diazo reproductions of the four MSS bands constructed a combination similar to that which was ultimately used.

FIGURE 19

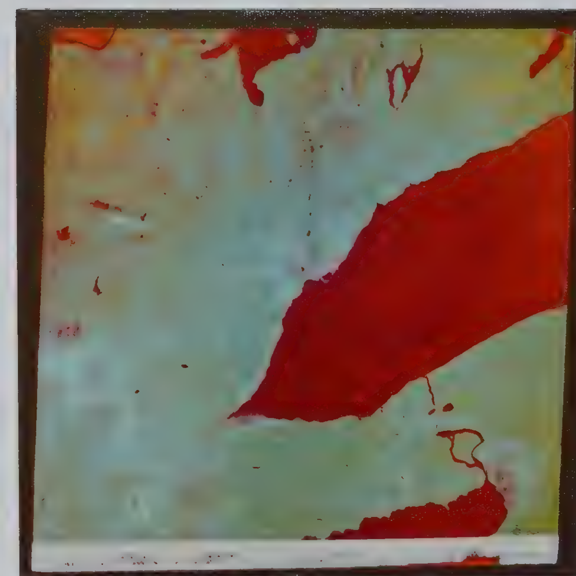
A PRELIMINARY LANDSAT MAP FOR THE TORONTO CENTRED REGION

Approximate Scale 1 to 2 Million

FIGURE 21

A NASA SIMULATION AND A DIAZO COLOUR COMPOSITE

NASA SIMULATION



DIAZO COLOUR COMPOSITE

The red — brown colour for water area in the Diazo composite was masked out for the final reproduction.

Approximate scale 1 to 3.3 Million

Having completed the preliminary investigations of image and map, the compilation and final design could start. Beginning with the original concept, the LANDSAT image was intended to be equally important as the map symbology. To accomplish this the maximum LANDSAT image scale (1:250,000) was used as well as a level of symbol generalization greater than that found on traditional maps of this scale. This combination intended to grant as much map area as possible for the LANDSAT image representation. The level of symbolization was comparable to that found in maps of 1:500,000. A factor of image generalization exists in all imagery; so, in every respect the image itself was also generalized. A combination image of three bands 4, 5, and 7 reduced this generalization. Once the theoretical level of generalization was finalized, compilation began, relying on available topographic maps at a scale of 1:50,000 and 1:250,000; but relying more heavily on interpretation of the actual LANDSAT image and supplemental high altitude aerial photography. Whenever possible the image itself determined the amount of simplification (i.e. the coastal boundary or the extent of urbanization).

4.4 Map Production

The conversion of the map design to a final printed format developed through several stages. After the initial compilation at the final scale the compiled sheets went to Lockwood Survey Corporation where they were converted to scribe sheet separations. Since some type and symbols appear in different colours such as blue and green, the pertinent line work was scribed on white scribecoat which later served as a base for stick up lettering. These were then photographed

producing a negative of both type and line work. Type such as highway designations and graticule markings were produced directly on scribe sheets using a Leroy scriber. When the scribe sheets were completed, they returned to Guelph for paste up and the production of the urbanized area mask. These sheets then went to Graphic Litho Plate Ltd. where working negatives, masks, and master negatives were constructed. A summary of the scribe sheets, masks, and working negatives appear as follows:

1. Graticule and Degree Markings were scribed on amber scribe coat to be used directly as a working negative.
2. All type to be produced in black was stuck up on stable base cronaflex and converted to a working negative.
3. Type for the blue lake and river designations was stuck up on the white scribed sheet of hydrography and photographed for a working negative.
4. Highways were also scribed on white scribecoat, airport annotation added, and then photographed to produce a working negative.
5. County boundaries were done by the same method on white scribecoat with type stuck up directly on the scribed sheet and photographed to produce a working negative.
6. A closed window mask of urbanized area was produced by hand on stable base cronaflex.
7. A closed window water mask was also produced using a negative of MSS Band 7.
8. Working negatives of MSS Bands 4, 5, and 7 already existed at this time in a halftone form.

The decision to use process colour instead of flat colour printing followed from a need to economize. Eight colours would need to be printed if a flat colour printing were to be used and that would require an extra run through a four colour press. Ultimately a five colour press would be used combining process colour with an extra blue colour printed. Consequently the final design was planned for printing black, blue, magenta, cyan, and yellow. The LANDSAT image bands were printed in magenta, cyan, and yellow using 150 line/inch screens of eighty-five percent. Map annotation used combinations of all colours. The working negatives, positives, and masks were brought together to produce the following printing design:

<u>Black Printing Plate</u>

combined elements: (for master negative exposure)
- graticule and grid annotation.......positive
- all type place names black ....positive

Produced master negative of: type and graticule ....negative

Printing: - graticule and type in 100% black (see figure 22)

<u>Blue Printing Plate</u>

combined elements: (for master negative exposure)
- hydrography .... combined on
- hydrography place names .... scribecoat

Produced master negative of: hydrography and type .... negative

Printing: - hydrography and type in 100% blue (see figure 22)

<u>Magenta Printing Plate</u>

combined elements: (for master negative exposure)
- 150 1/in halftone of MSS Band 4-85% screen ....negative
- highways and highway place names ....positive
- county boundaries and county place names ....negative

Produced master negative of:
- half tone of MSS Band 4 ....positive
- open window highways and place names ....negative
- closed window mask for county boundaries ....positive

Printing: - an 85% halftone image of MSS Band 4 in a negative form
- highways and highway place names in 100% magenta
- county boundaries and place names in 0% magenta or white, later to be printed in cyan and yellow (see figure 23)

Cyan Printing Plate

combined elements: (for master negative exposure)
- 150 1/in halftone of MSS Band 5-85% screen ....negative
- highways and highway place names ....negative
- county boundaries and county place names ....positive
- open window for urbanized area ....negative

Produced master negative of:
- halftone of MSS Band 5 ....positive
- closed window mask of highways and place names ....positive
- open window county boundaries and place names ....negative
- closed window mask of urbanized area ....positive

Printing: - an 85% halftone image of MSS Band 5 in a negative form
- highways in 0% blue to be printed by magenta
- county boundaries and place names in 100% cyan
- urbanized area in 0% cyan to be printed by magenta and yellow (see figure 24)

Yellow Printing Plate

combined elements: (for master negative exposure)
- 150 1/in halftone of MSS Band 7-85% screen ....negative
- highways and highway place names ....negative
- county boundaries and county place names ....positive
- open window for water area ....negative

Produced master negative of:
- halftone of MSS Band 7 ....positive
- closed window mask of highways and places names ....positive
- open window of county boundaries and place names ....negative
- closed window mask for water area ....positive

Printing: - an 85% halftone image of MSS Band 7 in a negative form
- highways in 0% yellow to be printed by magenta
- county boundaries and county place names in 100% yellow
- 0% yellow printed on water area, printed by cyan and magenta (see figure 25)

The final Toronto ERTS (LANDSAT) map design yielded a map not greatly dissimilar from a conventional thematic map of the same content and area. Yellow from Band 7 has been masked out of the water area leaving a more conventional blue with magenta highlighting sediment load. Negatives of the MSS images were used to maintain as much of the image information as possible but still mask out the oversaturated brown developed in the preliminary, image colour balance (see figure 20). Cities usually shown in some combination of pink or red or yellow on conventional maps are here displayed with a combined printing of magenta and yellow, the cyan being masked in the urbanised areas. The colour balance achieved created a yellow-green colour for woodland and dense vegetation. A darker green would be more appropriate for designating wooded swamps and river valleys, however, low lying areas would with conventional hypsometric tints be delineated by a lighter, more yellow green. This latter convention was utilized here as it provides greater contrast with the blue line detail overlain for hydrography and hydrography place names.

4.5 The Toronto Centre Region ERTS (LANDSAT) Map - Critique and Comparison

The Toronto map like the Washington D.C. and Ottawa maps has been published at a scale of 1:250,000 resulting in an image size of 29 inches by 29 1/2 inches printed on 200 lb. enamel coated paper with trimmed dimensions of 42 inches by 38 inches. Explanatory information concerning the satellite system, printing, and map design is printed

FIGURE 21

A COLOUR BALANCE PROOFING OF A SECTION OF THE TORONTO ERTS (LANDSAT) MAP

This proofing was produced from the working negatives and positives to test the colour balance before master negative construction. On the yellow-red version cyan has been masked from the land area.

FIGURE 22

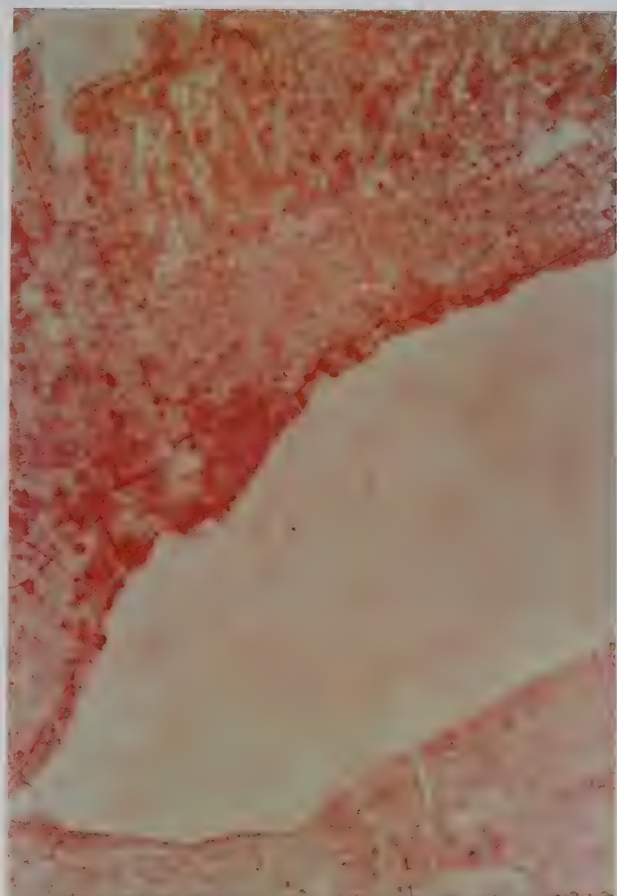
THE BLACK PLATE AND BLUE PLATE PROGRESSIVE PROOFS OF THE TORONTO ERTS (LANDSAT) MAP

BLACK

BLUE

FIGURE 23

THE MAGENTA AND MAGENTA PLUS YELLOW PROGRESSIVE PROOFS OF THE TORONTO ERTS (LANDSAT) MAP



MAGENTA

MAGENTA PLUS YELLOW

FIGURE 24

THE CYAN AND CYAN PLUS MAGENTA PROGRESSIVE PROOFS OF THE TORONTO ERTS (LANDSAT) MAP

CYAN

CYAN PLUS MAGENTA

FIGURE 25

THE YELLOW AND YELLOW PLUS CYAN PROGRESSIVE PROOFS OF THE TORONTO ERTS (LANDSAT) MAP

YELLOW

YELLOW PLUS CYAN

beside the image map as well as a small inset map of Southern Ontario indicating the location of image area. Unlike either the Washington D.C. Sheet or the Ottawa Sheet the Toronto LANDSAT map is not reproduced to simulate colour infrared photography. The negative printed images of MSS Bands 4, 5, and 7 are used to develop a colour balance approximating a natural landscape with some of the elements of hypsometric tinting. The map, first published for the Remote Sensing Symposium in May, 1974 at the University of Guelph is available through Donald Fisher and Associates Ltd., P.O. Box 1630, Prince Albert, Saskatchewan. A photoprint of the map appears in figure 26 and the map itself is included in the back flap as Map B.

Cartographic symbolization has been held to a minimum on this LANDSAT map, in respect to both simplicity and quantity. Only two kinds of point symbols are illustrated on the map, one crossed line symbol indicating the runways of major airports and a small orange square depicting the minor towns and villages. Apart from the grid, six line symbols are used; a conventional long dash, double dot international boundary symbol between U.S.A. and Canada printed in black, a standard 30 foot contour line for Lake Ontario bathymetric contours printed in blue; also printed in blue is a line symbol representing rivers and coastal boundaries; a single magenta line with open number symbols designates major highways, a green line delineates county and regional municipal boundaries; and finally a simple, single black line represents the Niagara Escarpment. The primary areal symbol portrays the extent of urbanized area, however, as with all LANDSAT maps a great deal of area symbolization is undertaken by the image. Scales of both miles and kilometres exist with

FIGURE 26

A PHOTOPRINT OF A SECTION OF THE TORONTO ERTS (LANDSAT) MAP

an additional cartographic note indicating the position error of image centre, necessary due to a lack of image precision processing. The grid clearly printed in black is graduated in degrees and minutes at intervals of thirty minutes for both longitude and latitude. An explanatory note beside the image-map stresses that the grid should also be viewed with reference to the position error. Type faces used on the map are conventional and rely heavily on simple sanserif styles of Univers and Mundus in both upper and lower case. The use of italic type is restricted to hydrographic features with Bodoni upper and lower case for river place names and New Headliner italic in upper case for major lakes. These latter type faces are the only two faces having serifs. Excluding title type sizes on the map range from six point to twenty-four point. The use of type size classifies features ordinally as would a topographic map at this scale. Although all symbols are named no legend exists on the map.

The Toronto ERTS (LANDSAT) map, differs from the two previous LANDSAT maps by having a major aeral extent component devoted to portraying urbanized area. Although effective when considering the contrast values of the orange urban area and surrounding "green" landscape a loss of detail in urban areas is apparent. This is brought about by the masking of MSS Band 5 (printed in cyan) from the urban areas. An exposure through an open window mask of the urban area detail from Band 5 could have been made with the result of printing both MSS Band 4 and MSS Band 5 in Magenta. This would have provided more detail allowing a greater image interpretation potential. Additionally the quality of the imagery itself is lacking. That fuzziness found in the Washington D.C. ERTS (LANDSAT) map is also

evident here. A certain amount of this is due to a band to band misregistration which could only have been solved by precision processing. However, the technique used in the Ottawa LANDSAT map of printing each spectral band in two colours might have improved the sharpness. Much image information is still usuable despite this lack of resolution. The general appearance of the image-map is more natural than its simulated infrared counterparts and the contrast between light green wooded valleys and their corresponding rivers is adequate and provides a clear representation. The illusion of hypsometric tints, on the other hand, is deceiving since the spectral responses are based more on vegetation regimes than actual elevations.

Cartographic symbology may be overgeneralized but if the quality of the image could have been improved this level of generalization would be acceptable and in review of the map objectives even better. The symbology can easily be visually classified in order of dominance or importance with the areal extent of urbanized area ranking first, Niagara Escarpment second, major highways third, and country boundaries of least importance. This latter symbol blends with the image and is inconspicuous but is easily read with close inspection. The lack of a legend is disturbing even though the majority of features are clearly labelled. The symbols themselves are very simple and cover as little of the image as is necessary. The symbol misregistration can only be attributed to improper or incomplete proofing and editing.

The Toronto ERTS (LANDSAT) map is the most thematic of the three maps discussed. The Washington D.C. ERTS (LANDSAT) map relies heavily on a topographic symbol representation while the Toronto ERTS (LANDSAT) map relies on the areal extent technique. The Ottawa LANDSAT map employs

virtually no enhancement relying heavily upon the image itself to carry the message. This reliance is not complete since only a section of the LANDSAT image is mapped. This section is extracted from the image and aligned to North producing "neat" graticules parallel to the map boundaries unlike the other LANDSAT maps; which maintain the graticule at an angle but cover the entire LANDSAT image area. The Toronto ERTS (LANDSAT) map again differs from the other image-maps in the production of a false colour "natural" landscape and by printing the negative MSS Bands instead of positives.

Maintaining few similarities, three different approaches to LANDSAT mapping or rather the use of the LANDSAT image as a mapping base, have been developed. The ideal approach appears to be a combination of all three. Each map has developed techniques which should improve the overall status of LANDSAT maps. The LANDSAT map at this scale is capable of supporting a large amount of cartographic enhancement as evidenced by the Washington D.C. map, even though in some cases it appears congested. A level of generalization less than that of conventional maps is still needed, however. Topographic map references of the comparative LANDSAT image area should be supplied on each LANDSAT map. The Toronto ERTS (LANDSAT) map has developed a useful approach to colour balance of the image. Although the infrared simulation is informative to a trained image interpreter, a more natural appearing image would be of greater use to a larger map audience. Other colour combinations could be achieved for particular thematic purposes providing sufficient explanatory information regarding the MSS Bands is given on the LANDSAT map. Image enhancement and clarity can be considerably improved by printing one MSS band in more than one colour

as with the Ottawa LANDSAT map. One drawback remains; if the LANDSAT map is to become successful, better processing techniques in image resolution and geometric fidelity need to become more accessable. Although image enhancement and precision processing techniques exist, the cost of such techniques still remain beyond the budgets of most potential users. This is not to say that the LANDSAT image in its present low cost, standard format could not be used as a mapping base at smaller scales with greater thematic content.

CHAPTER 5

THEMATIC LANDSAT MAPS

5.1 Introduction

As maps and map products have evolved with the development of new cartographic techniques and methodologies a need to establish a terminology to communicate those techniques arises. The first definitions must come with the maps themselves. Maps may be classified by many methods or approaches such as, map scale, or map data classification, or map purpose and audience. Although some systems are more generally accepted and some less, a useful and straight forward approach based primarily on map purpose and technique will be adopted here. Professor J.J. Klawe in 1973 developed an approach based on two general map categories, "balanced" and "weighted" maps. Balanced maps are maps in which all map elements are of equal importance. No map component whether human or physical is stressed or emphasized to the detriment of the other map elements. Topographic maps are classified in this category. Weighted maps, on the other hand, do emphasize particular aspects or topics in maps. These maps are more commonly called thematic maps and depict selected socio-economic or physical themes (i.e. population density or mean annual stream flow). Klawe combines this classification scheme with a previously accepted definition of cartographic methods (Ratajski, 1963) and produces a working classification system for thematic or "weighted" maps. The eight cartographic techniques are summarized by qualitative and

quantitative methods as follows:

Weighted or Thematic Maps

Nominal Data Ordinal Data	Qualitative Maps	Quantitative Maps	Interval Data Ratio Data
	1. Areal Extent 2. Symbol 3. Chorochromatic	4. Dot 5. Cartodiagram 6. Choropleth 7. Dasymetric 8. Isoline	

These nine basic mapping techniques or methods of representing data on maps are representative of all thematic mapping. As the discipline advances new techniques may be discovered but for the present all two dimensional, printed thematic maps use one or combinations of the above methods. Special methods have been developed for relief representation some of which have not been included here; such as relief shading. These techniques are more commonly used on balanced maps. For this study mapping techniques will be confined to statistical data representation and since the previous chapter employed on LANDSAT mapping at the 1:250,000 scale, smaller scales will be discussed here.

5.2 Conceptual Aspects of the LANDSAT Thematic Map

The ever increasing demand for more cartographic products, of better quality, and in less time requires that the cartographer of today be continually searching for new data sources, techniques, technological advances, essentially anything which will allow him a better communication for less money. Many such advances have been

adopted readily to the ultimate benefit of both cartographer and map reader. The development of the LANDSAT system is one of the more recent advances now available to the cartographer.

The LANDSAT image for many purposes provides not only an excellent data base but also an excellent data base-map. Compilation of an adequate base map for thematic objectives consumes considerable time, energy and funds. That exercise entails the selection of a suitable projection and the location and generalization of topographic features to be included for reference on the map. The LANDSAT image can be programmed to fit several projections, the most common being the Universal Transverse Mercator. This projection is already being used extensively on topographic maps from which base maps for thematic topics are often compiled. With selection of the most recent quality imagery the locational features supplied by the LANDSAT image are the most up to date possible and are frequently more exacting in both location and content. Generalization of the LANDSAT mapping base occurs in a uniquely conceptual area apart from that of conventional map generalization. Instead of deciding the degree of line and symbol generalization such as the simplification of a coastal boundary (this is already achieved by the imagery) the LANDSAT image requires generalization along two lines: the selection of the suitable MSS spectral band or bands, and the control and manipulation of positive-negative and/or composite images of those bands. Compilation and generalization of the hidden information (county boundaries, place names, etc.) and the thematic topic proceeds as with conventional, thematic maps.

Logically, the effectiveness of the LANDSAT image as a mapping base would be greatest when or if relationships between the thematic content and the LANDSAT image can be easily deciphered by the map user. This would require a degree of interpretative skills on the part of the map user. The complexity of the graphic image in some ways would be increased and the map user would be required to turn that complexity into a useful communication. This does not imply that the map user could not derive useful information from the more complex LANDSAT map. So few LANDSAT maps exist that the opportunity for evaluation of the LANDSAT image by the map user is virtually non-existent. A great deal of psychological and empirical testing is needed before an answer could surface. Such an investigation is beyond the scope of this study, however, preliminary research has been undertaken. Unlike conventional methods, no guidelines exist for the design and production of thematic LANDSAT maps. Through the production of thematic LANDSAT maps utilizing the basic cartographic methods the first steps towards development of those guidelines are undertaken.

5.3 Design and Production of Selected Thematic LANDSAT Maps

In chapters two and three considerable discussion was undertaken concerning the use of Areal Extent and Symbol or Alpha-numeric methods in conjunction with the LANDSAT images and will not be repeated here. The Dasymetric technique will also not be considered due to the extensive knowledge of the mapped area inherently required by the technique. In outward appearance the design of the dasymetric map is similar to those methods which classify the entire area of the map; chorochromatic, choropleth, and isarithmic. Economic reasons also

dictated a limit to the project and the three types of cartodiagrams were deemed to be of greater importance. Consequently additional LANDSAT maps were made utilizing the following cartographic methods: Chorochromatic; Dot; Cartodiagrams using flows, bar graphs, circle sector symbols, and graduated circles; Choropleth; and Isarithmic (Figures 27-34).

Compilation for each of the thematic LANDSAT maps was undertaken at a scale of 1:750,000. Standard 9 inch by 9 inch LANDSAT image film positives were enlarged to this scale and converted to negatives. Each of the images were then halftoned using a 110 lines per inch screen. The orthochromatic film sheets of the halftone images were used to produce Diazo colour images. Many different image colour combinations were combined with a thematic overlay and evaluated. The image was; however, in a monochrome of one or several bands. A monochrome instead of a false colour composite was used for three reasons: 1) At this early state in the development of the LANDSAT map it seemed best to anticipate possible design problems developing in the contrast between LANDSAT image and thematic representation. Consequently the LANDSAT image is held to a minimum level of map content leaving the maximum flexibility to communicate the thematic element which, of course, is the primary purpose of the map. The maintenance of this minimum level is also aided by using the negative image print on the maps.

2) Considering printing costs today, the most economical use of the LANDSAT image in thematic mapping is similar to the approach used for shaded relief plates; the use of a single colour, base image depicting the natural landscape with a map annotation overprint. The LANDSAT

image would not need to depict or represent the natural landscape, it records the natural landscape. 3) Cost.

The LANDSAT image, produced by both CCRS and NASA, when combined with the thematic overlays was used to simulate a printed map using a flat colour process. The thematic overlays were produced using a combination of Letratone shading film, coloured ink and stick up type produced by both impression and photographic type machines. The maps are essentially compile or preliminary maps to be used for evaluation before reproduction. A certain amount of image degradation is apparent in the photo prints of these manuscript maps, however, with a printed version this can be easily overcome (see Figures 27-34). The themes, themselves, were chosen to be representative of cartographic methods. Although compiled for the entire LANDSAT scene, the image-maps were squared to maintain a more conventional format.

CHOROCHROMATIC LANDSAT MAP

Physiography Toronto Centred Region

- 12 Element Thematic Overlay
- Black Halftone Image, Single MSS Band

The large number of classifications on the Physiography LANDSAT map demands not only a monochrome form of LANDSAT image but a monochrome of a neutral shade or colour. A halftoned black/grey LANDSAT image provides the base for this map. A careful selection of hues for the classifications is mandatory since their appearance will alter with the varying amount of black added by the image. Additionally if hues are too similar the possibility of category confusion arises (See Till Plains - drumlinized and Shale Plains, Figure 27). Care must also be taken to preserve the illusion of transparency; if the

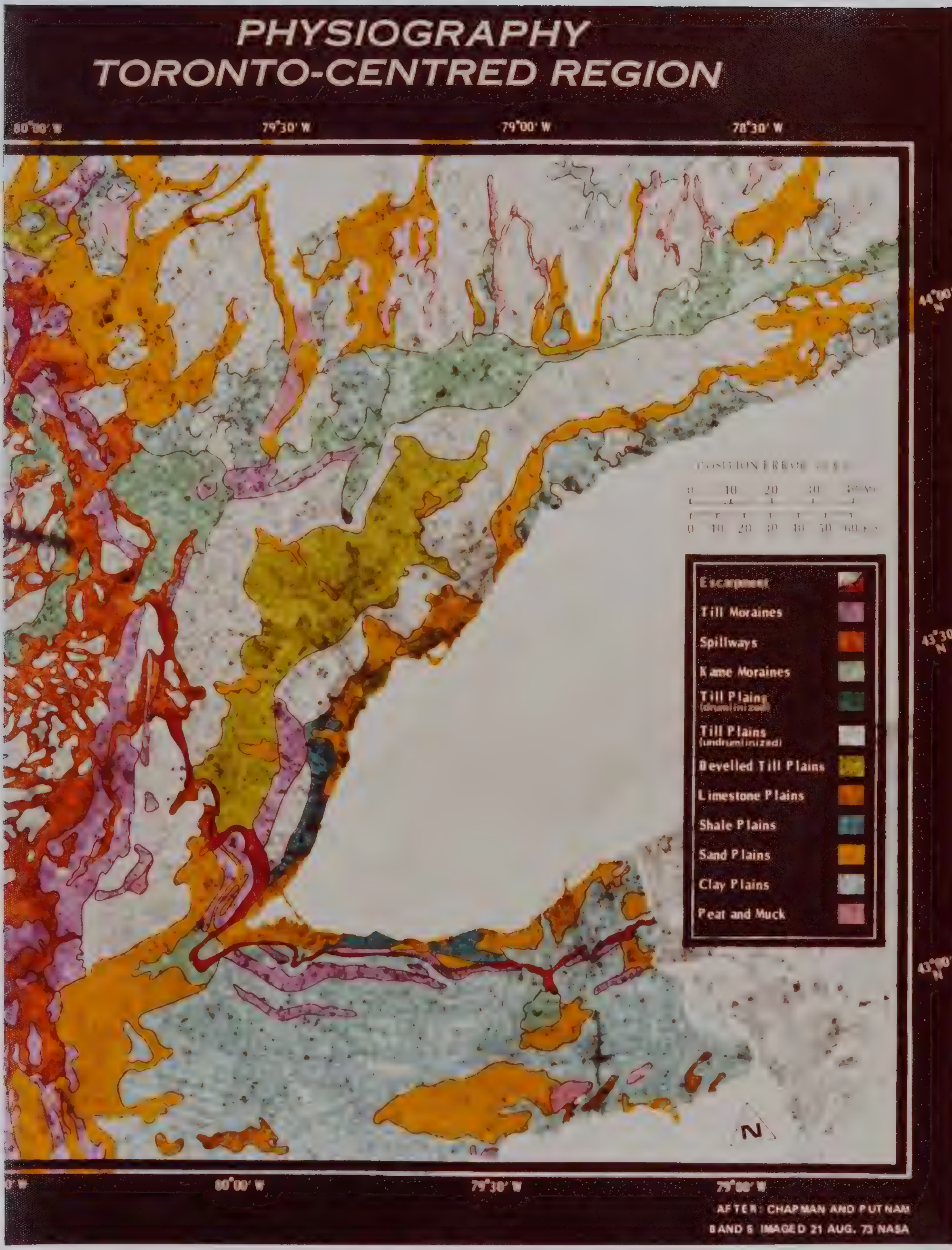


FIGURE 27

AN EXPERIMENTAL CHOROCHROMATIC LANDSAT MAP

LANDSAT image is to function it must be seen. A balance between image and map elements must be achieved. If the colour overlay is too saturated the combination of that category colour and image detail could produce a dark unreadable area, as in the "Shale Plains"/"Till Plains" in Figure 27, even though the areal extent of these categories is still communicated the information supplied by the LANDSAT image is lost. The individual categories in the legend are produced from a segment of image extracted from a duplicate image and reproduced here with the thematic colour overprint. The image segments are extracted from areas that are indicative of the actual map classification (i.e. the image for a section of "Sand Plains" was extracted from a Sand Plain area on the image). The categories in the legend should be as indicative of the actual area on the LANDSAT map as is physically possible, a point confirmed by other LANDSAT maps. The high number of categories make the design of the LANDSAT map difficult for complete communication. The complete classification of the image area functions well provided the image itself has sufficient contrast.

LANDSAT IMAGE DOT MAP

Population Distribution Winnipeg Area 1971

- 2 Element Thematic Overlay
- Green Halftoned Image of Band 6

The LANDSAT Dot Map, as in Figure 28, has only two thematic elements to be communicated in conjunction with the LANDSAT image, a line element representing census division boundaries and the dot representation of population. The dot map, although relatively simple in design does take on some of the traits of the previous chorochromatic map; all of the map area is classified by the image. Gross, nominal

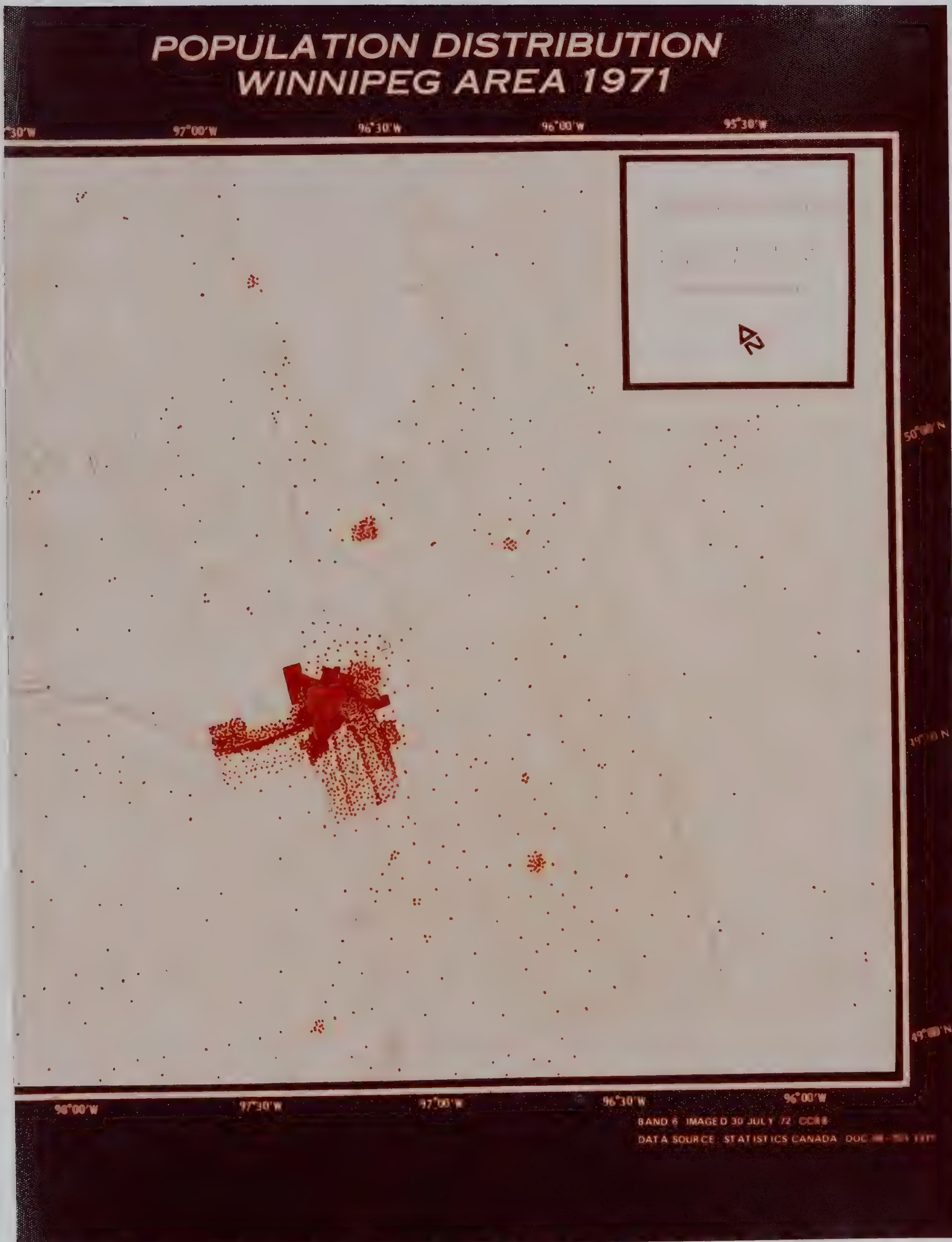


FIGURE 28

AN EXPERIMENTAL LANDSAT DOT MAP

categories of landscape such as shield area, farming areas, and urbanized areas are easily detected on the image. In the LANDSAT Dot Map the distinctive urbanized area patterns produced by the imagery are virtually obliterated by the coalescing dots. This can hardly be avoided since the coalescence is needed for the dot communication on any dot map not just the LANDSAT dot map. The two remaining areas do provide a visual correlation relating a very generalized land use to location of population. The alternative provided by conventional symbolization would have blank or white areas providing little information to the map user. Careful consideration must be given to contrast levels between image and dot. It the dot isn't prominent, it could be entirely lost within the LANDSAT image. Consequently, the selection of hue for both image and dot is most important.

LANDSAT FLOW MAP

Mean Annual Stream Flow Toronto Centred Region

- 2 Thematic Elements
- Magenta Halftone Image, Band 5

Unfortunately the LANDSAT image does not record some features at a suitable contrast level for mapping purposes. Some elements or themes such as hydrography, appearing as a black overprint on Figure 29, are for the most part interpretable on the LANDSAT image and can nearly always be detected by a pixel printout map; but conventional image processing doesn't develop a level of contrast suitable for thematic representation. Consequently the need arises for the cartographic enhancement of the major river and stream network. Considering the contrast level of the image this enhancement needs to be continued for the lake shore boundaries as well. Another method of alleviating this problem would be to print an image combining two MSS Bands, Band 5 for

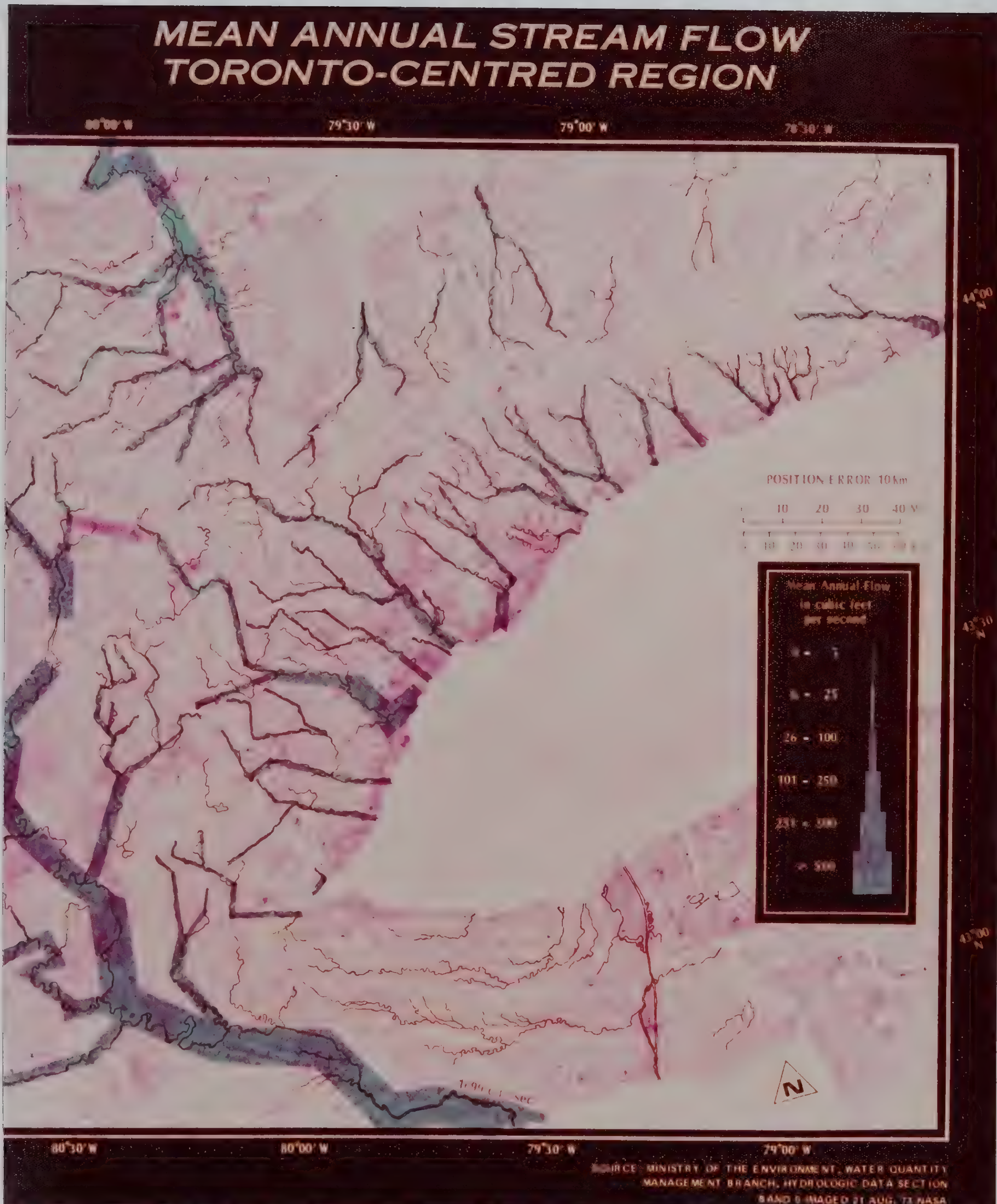


FIGURE 29

AN EXPERIMENTAL LANDSAT FLOW MAP

topographic and cultural features and Band 7 to delineate coastline boundaries.

The thematic component is once again occupying the dominant graphic role. The graduated stream flow representation is transparent, allowing the image to be viewed, but at the same time the contrast is great enough to be easily read. Due to the simplicity of the stream graduation symbol the legend is easily decoded even though the symbol in the legend does not utilize a LANDSAT image print extracted from the stream area on the image as in Figure 27.

CHOROPLETH LANDSAT MAP

Residential Intermittment Hydro Customers Lake Simcoe Region 1970

- 6 Thematic Elements
- Green Halftone Image, Combined Bands 4, 5, 6.

This LANDSAT map stresses the fact that the categories in the legend must appear with the appropriate area of the LANDSAT image as an underprint. The alteration of colour by the LANDSAT image is considerable and must be taken into account. The legend is completely unusuable unless it can relate the legend classification to actual map area. The choroplethic classes are easily distinguishable within the six category series but there remains a considerable variation of brightness within the categories as the landscape recorded by the image changes. Although this variation in brightness cannot be eliminated, to facilitate map interpretation by the user, sections of the LANDSAT image must be included in the appropriate maps legend categories. A portion of this change in brightness also develops as a function of the cartographic method and thematic topic. The original map uses a black/grey image, however, this hue has been

FIGURE 30

AN EXPERIMENTAL CHOROPLETH LANDSAT MAP

altered by photographic reproduction. Unlike the chorochromatic map's use of boundaries delineated by physical features the choropleth map uses census boundaries which quite often do not correspond to variations in the physical landscape. However, the shield area and accessability to lake shore boundaries can be visually correlated to high density areas of intermittent hydro customers.

The resolution of this image exceeds that of the previous LANDSAT maps for two reasons. The image is a combination of MSS Bands and a image quality from CCRS processing is also superior for this particular scene. The image in this map appears of equal if not greater dominance than the thematic component.

CARTODIAGRAM LANDSAT MAPS

Building Permits Issued Lake Simcoe Region 1973

Steam and Hydro - Electric Power The Vancouver Region 1972

Population Distribution Toronto Centred Region 1971

- 2 Thematic Map Elements on each map
- Two maps use combinations of Bands 4, 5, 6; the third uses Band 5

The first map, Building Permits Issued - Lake Simcoe Region, applies a bar graph with six categories to aggregate data for each township census division. The image is the same one used for the CHOROPLETH LANDSAT MAP, however, it is illustrated by a less dominant, violet halftoned image. This image could be greatly increased in saturation without appreciable effect on the thematic representation (see Figure 31).

The circle sector map for electric power in the Vancouver Region uses a minimal saturation, cyan LANDSAT image to depict the physical landscape. Again there is no problem reading the thematic sector

FIGURE 31

AN EXPERIMENTAL CARTODIAGRAM LANDSAT MAP
UTILIZING BAR GRAPHS

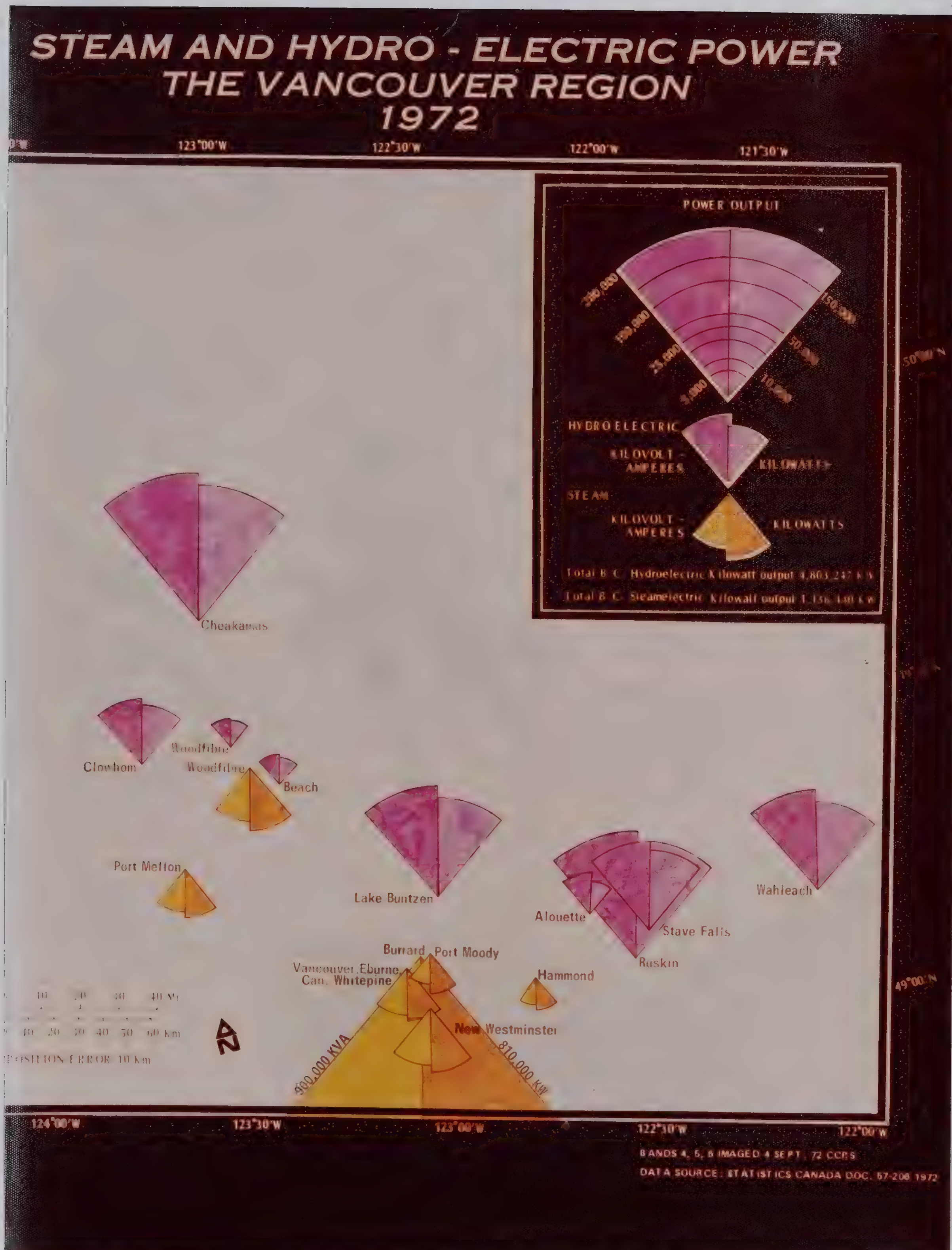


FIGURE 32

AN EXPERIMENTAL CARTODIAGRAM LANDSAT MAP
UTILIZING CIRCLE SECTORS

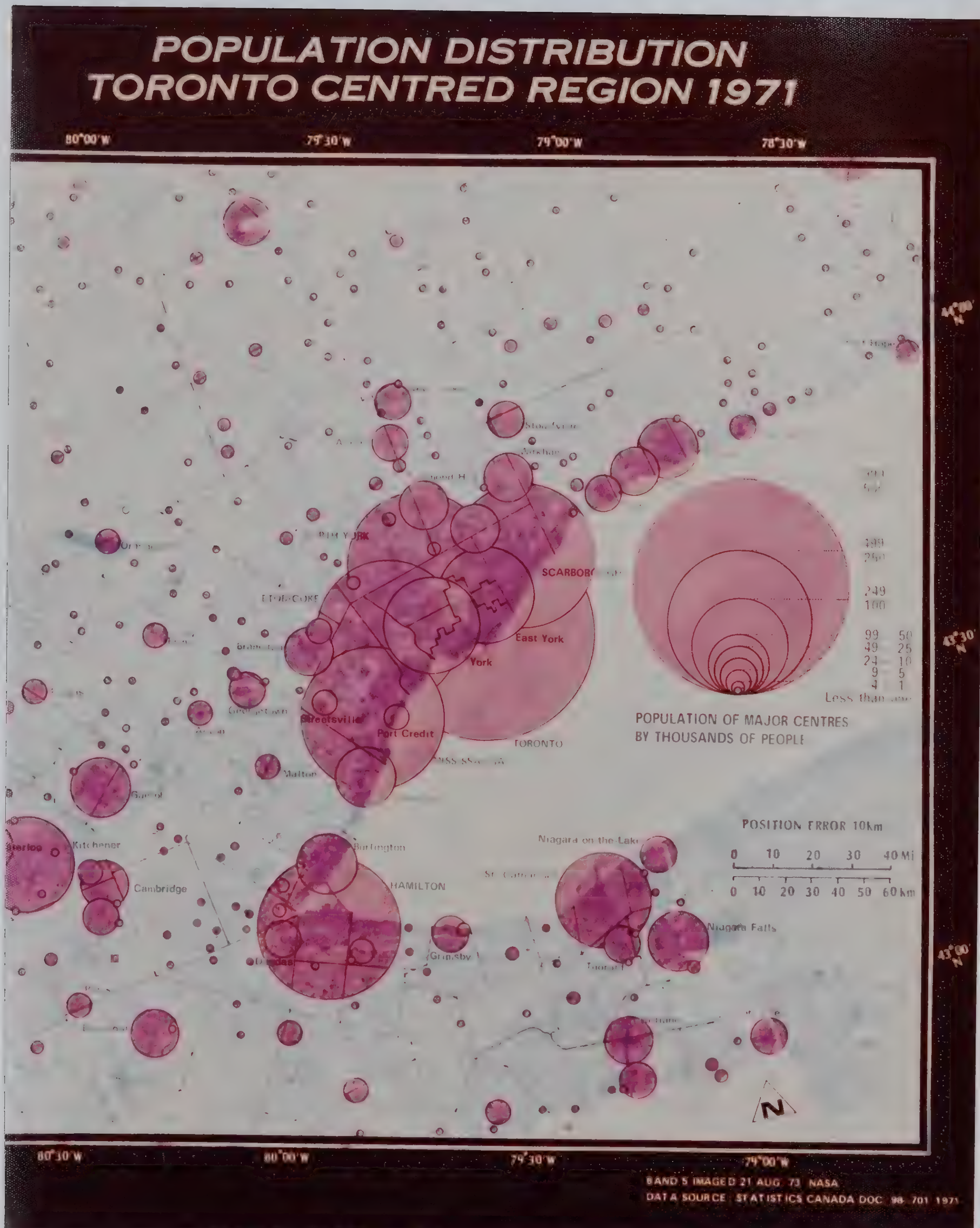


FIGURE 33

AN EXPERIMENTAL CARTODIAGRAM LANDSAT MAP
UTILIZING GRADUATED CIRCLES

symbols but the detail supplied by the LANDSAT image needs to be increased. For this map, particularly for the depiction of the glacier or snow covered areas (symbolized by the darker cyan in the image) a positive image would have been more suited. The map audience does, however, receive an impression of the watershed areas upstream from the hydro electric plants and should also be capable of correlating the large steam generating output with the Greater Vancouver Area (see Figure 32).

The graduated circle LANDSAT map of population distribution in the Toronto Centred Region appears here, as the most effective cartodiagram LANDSAT map representation. It combines township boundaries, graduated circles (in pink) and the LANDSAT image (in a blue halftone). The darker blue areas created by the spectral response of the urbanized areas in the image combined with the pink graduated circles tends to emphasize the urban area boundaries. The facility to evaluate and compare the actual size of urbanized area with the size of population is readily available (see Figure 33).

All of the cartodiagram techniques offer less difficulties in design and construction of LANDSAT image maps than those techniques requiring the classification of the entire LANDSAT image area. This is due to the well defined boundaries and shapes of the cartodiagrams and the greater design flexibility offered by mapping only two or three discrete thematic elements.

ISARITHMIC LANDSAT MAP

Population Density Toronto-Centred Region 1971

- 4 Thematic Elements
- Violet Halftone Image, Band 5

Two types of isarithmic maps exist, isometric and isopleth. The

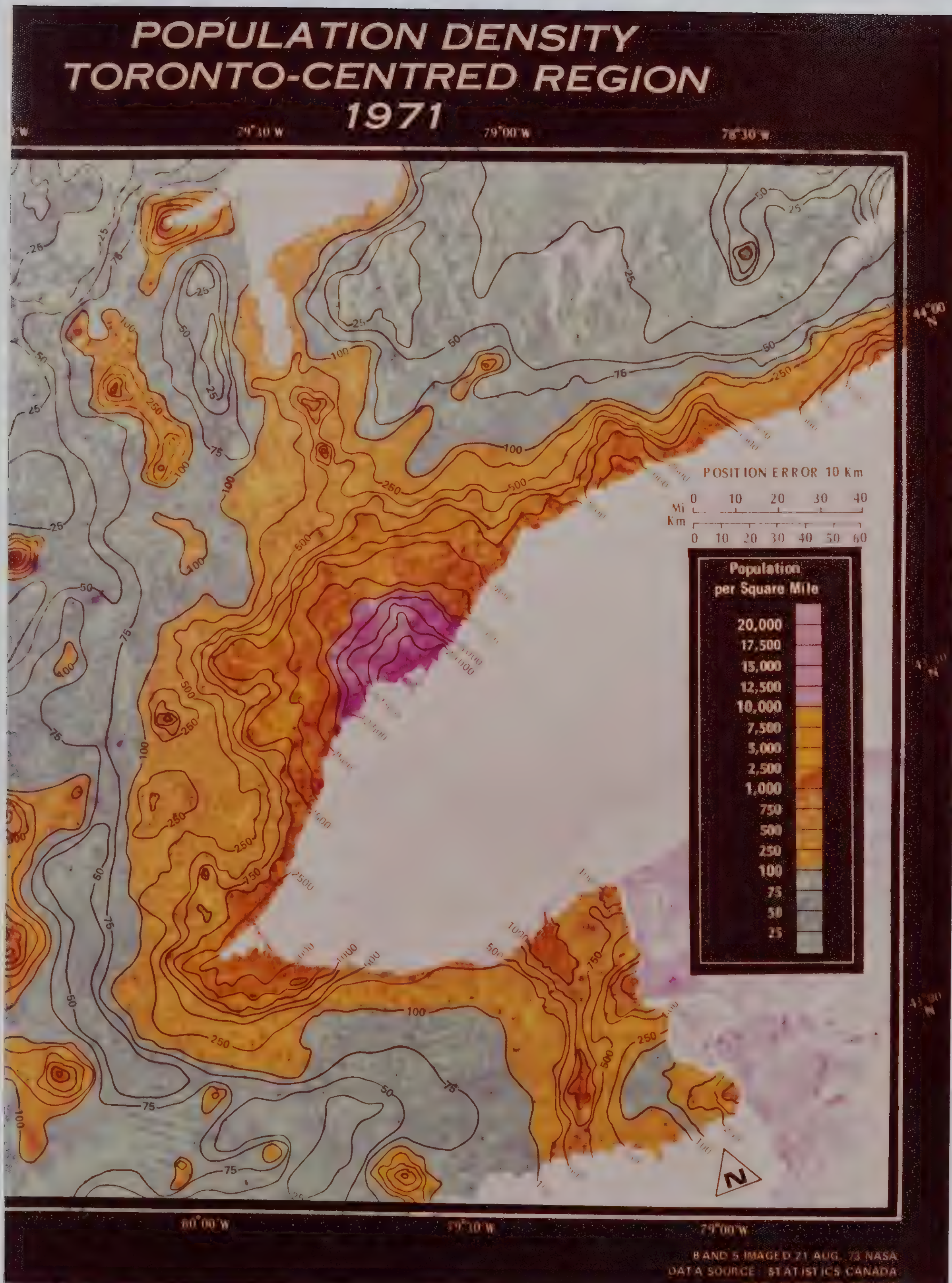


FIGURE 34

AN EXPERIMENTAL ISARITHMIC LANDSAT MAP
UTILIZING ISOPLETH LINES

difference originates in the accuracy of plotting data values rather than in the graphic design or map appearance; both use an isoline representation. The Toronto-Centred Region population density map utilizes the isopleth method with data points derived from township and incorporated city population densities. Isopleth tints have also been added to the map. These four layer shadings have class boundaries of 100, 1000, 10,000 people per square mile (see Figure 34). Green is used for the lowest population category with yellow and orange for increasing density, concluding with magenta for the highest population. A violet halftone image provides the image base. This combination produces a suitable contrast configuration for the map. The added detail supplied by the LANDSAT image in the urban areas tends to promote this layer shading effect by providing the illusion of depth. The legend once again illustrates the need to use an actual image underprint for the correct classification. The category division at 1000 people/sq. mile is a critical one and its communication is severely impaired by the lack of image detail. Several colour combinations were attempted for the actual isoline but the reversion to black ultimately provided the best contrast. Just as with the other maps classifying the total image area proper selection of image and thematic overlay colours is necessary.

5.4 Economic Aspects of Thematic LANDSAT Maps

Taking into consideration the cost of the LANDSAT image in photographic form and its inherent adaptability the cost of an LANDSAT map shouldn't amount to much more than the expense of an extra printed image. In many instances the cost of compile time in man hours can actually be reduced and the amount of compile time for the thematic

element is not going to be larger than that of a conventional map. The selection of suitable colour contrasts for map image and LANDSAT image could be time consuming but cost would diminish with more LANDSAT mapping experience. If the LANDSAT image were to be treated as conventional shaded relief plates are on maps today, the cost would be minimal. Pragmatically the LANDSAT image could function in just that way; as an additional clarifying element of the mapped topic.

The LANDSAT image also has considerable potential for automation of the thematic LANDSAT map. At the present time programs exist for the extraction of generalized landuse patterns from LANDSAT data (Ellefsen, 1974; Joyce, 1974). Automatic thematic LANDSAT mapping could be carried further with the establishment of a library of computer produced map symbols (Peucker, 1972; Linders, 1973). This library in conjunction with a statistical data bank could automate the entire process. The computer could receive the LANDSAT Data directly from the satellite; process and record the image on a fitted grid (Chapman 1974; Hooper, 1974); sort the appropriate statistics from a data bank for the relevant census divisions included on the image; reproduced the established map symbology in conjunction with the LANDSAT image; all to be displayed by a cathode ray tube viewer. This is a projection of one possible approach to thematic LANDSAT mapping which would require considerable funding.

Another more realistic economic approach incorporates the direct use of the LANDSAT image/photograph, ordinarily available at minimal cost. The manuscript map of this chapter are intended to illustrate maps this type of use. This avenue to thematic LANDSAT mapping could conveniently be exploited by thematic cartographers with limited budgets.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS FOR THEMATIC LANDSAT MAPS

6.1 Best Use of the Thematic LANDSAT Map

The development of thematic LANDSAT mapping can occur along two channels: one having ultimate long term benefits and the other using available imagery, now. The longer range plan could incorporate a completely automated, digital mapping scheme. LANDSAT data could be received, processed, combined with statistical data and displayed by the computer. With a television display, facility for adjustment of image to map contrast, generalization, and symbolization could be left in the hands of individual map users. This capacity combined with pre-established formats and combinations of image-maps stored in the computer could revolutionize our concept of the map. As computer technology develops, the automated LANDSAT maps will become more of a reality.

The more conventional use of thematic LANDSAT maps utilizing standard photographic image products shows great promise. These photo-maps can be produced quickly and cheaply but its success will depend upon the map users reaction to the photo element of the map. If he can successfully interpret image data and incorporate that information into his concept of the thematic topic then "reality" will be incorporated in the thematic map. In any event the LANDSAT map will not replace the conventional representation; but if used wisely in conjunction with conventional maps should supply additional data to the map user.

6.2 Conclusions and Design Guidelines for Thematic LANDSAT Maps

Several LANDSAT mapping experiments have been undertaken in an attempt to develop guidelines for the design and construction of thematic LANDSAT maps. These empirical endeavors, far from being exhaustive, were intended to promote further research and develop a concept of the problem areas. The following guidelines will hopefully aid those ventures.

1) The comparison of thematic LANDSAT mapping scales points the direction for future LANDSAT maps. The three 1:250,000 LANDSAT maps are all somewhat lacking in image detail. Many features interpretable on the LANDSAT image leave much to be desired when placed in a map situation. Indeed, an image of exceptional quality is needed before enlargement to this 1:250,000 scale should be attempted. Furthermore, the geometric fidelity of the image has a difficult time meeting map accuracy standards for this scale. Recent investigations (Wong, 1975) indicate that the LANDSAT image can now easily meet map accuracy standards for enlargements to 1:500,000. Considering the majority of thematic uses the 1:500,000 to 1:1,000,000 mapping scale of the LANDSAT image is ideal for the production of the smaller scale thematic, photo maps. This has not been feasible in the past due to prohibitive costs. Essentially a new area of cartography is opened for development.

2) The construction and evaluation of the different cartographic methods indicates some techniques used for thematic representation are more readily adapted to the LANDSAT image than others. Methods using areas to delineate spatial distributions proved extremely difficult for development of suitable designs. These techniques employing a classification of area on the LANDSAT image rely on an overprinted

colour to depict the distribution rather than masking colour as well as detail from the image; which proved to be unacceptable. These techniques include areal extent, chorochromatic, choropleth, and the hypsometric tinting on the isopleth map. In all cases the design problems are not insurmountable but with a large number of theme classifications they multiply rapidly, particularly if communication is dependent solely upon the colour overprint. These coloured areas prove difficult to interpret when combined with the image as the variations of image density change the brightness and sometimes hue and saturation of the coloured area. This problem is reduced when homogeneous areas detected on the imagery relate directly to the thematic area, or when categories can be held to a minimum, or when an additional design element such as a prominent isoline is relied upon for the majority of communication. The dot, flow, and cartodiagram methods proved to be more adaptable to the LANDSAT image. Greater flexibility is available for the development of suitable contrast levels when fewer, more well defined, thematic elements are used as with these latter methods.

3) With any map representation, suitable contrast is needed for communication; this is of paramount importance when designing LANDSAT maps. Unlike conventional symbolization the entire area of the LANDSAT map is classified, if not by the thematic symbol, by the image itself. Since the symbology combines with the image for communication of themes, this combination must be of sufficient contrast for communication. At the same time the enhanced symbology cannot be so prominent as to disallow communication of the image information. For the LANDSAT map to function effectively a suitable balance must be achieved between

image and symbology. This is attained by developing appropriate contrast on three levels: contrast between image and paper, contrast between thematic element and image, and contrast of combined image-theme with other image-themes. The development of sufficient contrast between theme and image is more easily achieved with a monochrome image as opposed to a colour composite image in which, contrast must be established between each colour and the thematic elements. The contrast of the image is improved by using MSS Band combinations in a monochrome and by increasing the colour saturation of the image. The problem of contrast variation caused by the changing density levels in imagery is reduced but not completely eliminated by using "neutral" colours of image underprints. The change in brightness of thematic colours is minimized by using violet and black images. Other colours develop changes in hue and saturation. This deficiency of less consequence when only a few, well defined, map elements are portrayed.

4) All photo maps required an appropriate level of map annotation. The level is a function of scale, purpose and the amount of visual noise produced by the image. For symbol maps at larger scales the level is reduced. More generalization than on conventional maps is still needed. Other cartographic methods require little simplification, if any, compared to conventional thematic maps provided interpretation of image and symbology is maintained. This is accomplished by the transparency of the thematic symbolization. As well, thematic symbols are generally so specialized that unwanted map notation has already been removed.

6.3 Recommendations for Future Study

LANDSAT data offer the cartographer and map user a new dimension in thematic mapping. It is now possible to relate abstract thematic information at medium and small scale to an actual view of the Earth. The regional view supplied by LANDSAT I is an inexpensive, effective method of bringing "reality" back into thematic maps. The thematic LANDSAT map, a combination of conventional thematic mapping techniques and the LANDSAT image as a mapping base, provides a new tool for geographic understanding by the map audience and a new method of expediting thematic map production by the cartographer.

Sophisticated television displays may someday be freely available to a majority of map users, but most likely will not be available for years to come. This necessitates further experimentation into the printed version of the LANDSAT map. Theoretically and economically the printed thematic LANDSAT map is most effective but the communicative effectiveness can only be determined by perceptual studies including extensive map user evaluations. Future investiga-ors should put more emphasis on perceptual studies of this new map form.

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GLOSSARY

Across-track - across the direction of spacecraft ground track; sometimes called horizontal when referring to output product coordinates.

Along-track - in the direction of the spacecraft ground track; sometimes called vertical when referring to output product coordinates.

Altitude - the distance from the nadir ground point to the spacecraft.

Brightness - that aspect of the perception of a patch of light as the intensity (quanta per second per unit of retinal area) varies.

Bulk Processing Subsystem - see Initial Image Generating Subsystem.

CCRS - Canada Centre for Remote Sensing.

CCT - computer compatable tape.

Channel - there are 6 channels (scan-line detectors) per MSS spectral Bands 1, 2, 3, and 4; hence the MSS is a 24-channel scanner on LANDSAT I and II.

Digital Subsystem (formerly Special Processing Subsystem) - receives digitized image data from system correction and scene correction processing and produces digital image data in 7-track and 9-track, computer-compatible, magnetic-tape format.

EBIR - Electron Beam Image Recorder - A device using an electron beam to record digital MSS data on photographic film.

ERTS - EARTH RESOURCES TECHNOLOGY SATELLITE A and B, now termed LANDSAT I and II.

Format Center - the center of the RBV and MSS total image writing area in Bulk Processing. MSS Format Center is identical to RBV Format Center; defined as the intersection of the film registration mark diagonals. The image is corrected so that the geometric extension of the spacecraft axis to the earth's surface occurs at the Format Center.

Geometric Accuracy

Geographic (Latitude-Longitude) - based on the standard earth-fixed coordinate reference system, which employs latitude and longitude.

Positional - the ability to locate a point in an image with respect to a map.

Scene Registration - the ability to superimpose the same point in two images of a scene taken at the same time (different spectral bands).

Temporal Registration - the ability to superimpose a point in two images of the same scene taken at different times (same or different spectral bands).

Ground Control Point - any point that has a known location on the earth's surface which can be identified in ERTS imagery.

Ground Track/Trace - the locus of earth surface points which pass directly under the vehicle as it orbits the earth.

Hue - that aspect of the perception of light that varies when the wavelength is changed.

Image/Frame - that data from one spectral band of one sensor for a nominal framing area of the earth's surface.

Image Processing Subsystem - receives video data, image annotation, and correction data to produce both film imagery and digital image data.

Initial Image Generating Subsystem (formerly Bulk Processing Subsystem) - converts all video data from RBV and MSS sensors to 55 by 55 (or 53) mm annotated and corrected images, on 70 mm film.

LANDSAT - as of May 1975, the name applied to the Earth Resources Technology Satellite System. LANDSAT I was launched in July 1972 and LANDSAT was launched in January 1975.

LBIR - Laser Beam Image Recorder, a device using a Laser Beam to record MSS images on photographic film.

NASA - National Aeronautics and Space Administration.

Nadir - the intersection with the earth's surface of a line from the spacecraft perpendicular to the nearest plane tangent to the earth ellipsoid.

Negative - a photographic image on film, plate, or paper, in which the tones are reversed.

Negative colour - a photographic image on film, plate paper, in which the colours appear as the complements of those in nature.

Noise - any signal, manifested in any form of energy, that occurs irregularly with respect to the signal of interest, and tends to obscure that signal.

Mosaic - an assemblage of overlapping aerial photographs whose edges have been matched to form a continuous photographic representation of a portion of the earth's surface.

Mask - any material used over a print or negative to shield from exposure or printing a portion of the image.

Observation/Scene - the collection of the image data of one nominal framing area of the earth's surface; this includes all data from each spectral band of each sensor.

Orthophotograph - a photograph of the earth showing images of objects in their true orthographic positions. Orthophotos are produced from perspective photos by differential rectification which eliminates image dispacement due to photographic tilt and relief.

Pixel - the instantaneous field of view of a detector in a Multispectral Scanner.

Platform - a Data Collection System sensor package on the earth's surface.

Precision Processing Subsystem - see Scene Correcting Subsystem.

Precision Processing Subsystem (PPS) - the PPS receives user-selected, Bulk-Processed imagery and produces precision-located and corrected imagery on 9-1/2 inch (241.3 mm) film.

Principal Point - the intersection with the earth's surface of a line which is an extension of the optical axis of an RBV camera. This point differs from the format center by the boresight angle error from nominal alignment.

Radiometric - concerned with the combined electronic and optical transmission of data.

RBV - Return Beam Vidicon camera system.

Registration Marks - locations on the film plane outside the image writing area of Bulk Processing; there are four marks, one outside each corner of the writing area, fixed in position such that their diagonals intersect at the format center, or center of the tick mark coordinate center.

Reseau - the rectangular grid pattern inscribed on the RBV faceplate to facilitate geographic identification.

Saturation - that aspect of the perception of a patch of light that varies as more and more white light is added to a monochromatic light.

Scene Correcting Subsystem (formerly Precision Processing Subsystem) - receives user-selected, system-correcting imagery and produces precision-located; scene-corrected imagery on 9-1/2 inch (241.3 mm) film.

Sensor/Band Identification - the RBV spectral bands are identified as Bands 1, 2, and 3; the MSS as Bands 1, 2, 3, 4, and 5.

Skew - image distortion caused by scanning the scene in a direction non-parallel to the plane formed by the spacecraft and the instantaneous ground track velocity vector.

Special Processing Subsystem (SPS) - the SPS receives digitized image data from Bulk and Precision Processing and produces digital image data in a computer-compatible format.

Subsatellite Point - the intersection with the earth's surface of a line from the spacecraft to the center of the earth.

Sun Azimuth Angle - angle in degrees measured in the horizon plane from true north to a vertical circle passing through the sun.

Sun Elevation Angle - angle of the sun above the horizon measured in degrees.

Swath - the dimension on the ground seen as transverse to spacecraft velocity, within the sensor field of view (FOV).

Temporal - that which exists in the physical world as it relates to time but is not spatial, such as telemetry information.

Tick Marks - positional marks placed on imagery to enable a locational grid coordinate system to be constructed.

Tone - each distinguishable shade variation from black to white.

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